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Management of Subalpine Forests: Building on 50 Years of Research

Proceedings of a Technical Conference

Silver Creek, Colorado

July 6-9, 1987

USDA Forest Service
General Technical Report RM-149

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Management of Subalpine Forests: Building on 50 Years of Research[1]

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Technical Coordinators:
Charles A. Troendle
Merrill R. Kaufmann
R. H. Hamre
Robert P. Winokur

[1]These proceedings were compiled and produced in cooperation with the Society of American Foresters, and also are designated as their publication number SAF 87.08.

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Foreword

This summer marked the 50th anniversary of the Fraser Experimental Forest. These proceedings are the tangible product of the technical conference called to summarize, discuss, and transfer the knowledge learned over these 50 years. Eighteen formal papers describe the status of our knowledge about the interactions among timber, water, and wildlife. These papers were designed to present a balance of perspectives between research knowledge gained, and how that knowledge is actually being applied by forest managesrs and other resource specialists.

To broaden the scope of the conference -- and these proceedings -- 25 poster papers were also presented describing research in the subalpine environment in other ecosystems or for other resources. In total, the collection of papers in this volume is a good summary of state-of-the-art in understanding and managing the subalpine environment.

These proceedings are not only a statement of where we have been and where we are, but also present a glimpse of where we are going. In the past, research and management have been most concerned with resource response to impact. Today, we are equally or more concerned with a broader scope of human interaction with the environment and resource response to any potential environmental changes caused by man. This concern is evident in many of the papers that deal with recent, current, or proposed research, and may very well provide the base for the next technical conference on subalpine ecosystems.

The technical coordinators of these proceedings particularly want to acknowledge Sam Krammes for his initial planning efforts, and the speakers and attendees for their active participation and input during the conference itself.

Authors have propvided copies of their papers in electronic media form to expedite publication. The views expressed in these proceedings are the authors., and do not necessarily represent those of the U.S. Department of Agriculture.

Solicited Papers

Rocky Mountain Station Director, Charles M. Loveless (left), and Robert R. Alexander, Project Leader and long-time scientist at the Fraser Experimental Forest.

Early History of St. Louis Creek and the Fraser Experimental Forest: A Narrative

Robert R. Alexander[1]

Abstract--The early history of the St. Louis Creek drainage and the Fraser Experimental Forest is described in a narrative. Included are the establishment of the National Forests in 1908, logging by railroad and flume, and logging camps in the early 1900s, acquisition of private lands, establishment of the Fraser Experimental Forest in 1937, construction of the headquarters complex, research activities from the early days of the Experimental Forest to the present, and personnel that have worked on the Fraser Experimental Forest in the past 50 years.

Before Establishment of the Fraser Experimental Forest

Although Indians, probably Utes and possibly Arapahos, undoubtedly entered the St. Louis Creek drainage from time to time before the arrival of the white man, they left little or no visible evidence of their presence. With the settlement of the West, however, miners and trappers came into the valley in the late 1800s. Numerous ruins of mine shafts and cabins attest to their presence.

The earliest recorded mining claims near St. Louis Pass date from the early 1900s. Most of the miners were looking for gold, but found lead, zinc, and silver. In addition to those claims near St. Louis Pass, early miners were active in the Iron and Mine Creek drainages (fig. 1). Mining continued on a limited basis in upper Mine Creek through the 1950s. However, the volume of ore extracted was never high enough to warrant extensive operations.

The Fraser Experimental Forest was withdrawn from mineral entry in the early 1950s, and today there is no mining activity on the Forest.

On May 12, 1905, that part of St. Louis Creek drainage that lies north of Sections 32, 33, 34, and 35, T1S, R76W, 6PM was set aside as part of the Leadville Forest Reserve. The Leadville Reserve included southern Grand County from Kremmling, Hot Sulpher Springs, Fraser, and east to the Continental Divide. On July 1, 1908, it became part of the Arapaho National Forest when that Forest was established. The land north of that line was in private ownership at the beginning of this century.

[1]Chief Silviculturist and Project Leader in charge of the Fraser Experimental Forest, Rocky Mountain Forest and Range Experiment Station. Station headquarters is in Fort Collins, in cooperation with Colorado State University.

Logging began in this area (now part of the Fraser Experimental Forest) in 1906. A standard gauge logging railroad was built from the sawmill (established in 1906) located above the town of Fraser into the area to remove the timber harvested. The area that is now part of the Fraser Experimental Forest was part of 5,000 acres of forest land owned or leased by the Middle Park Lumber Co., operators of the mill. Although most logs were transported to the mill on flatcars (fig. 2) for manufacture, some rough lumber milled on site also was hauled. The railroad grade followed the present main road from the town of Fraser to the hill above the bridge crossing St. Louis Creek, turned west along a bench, and then south into the area northwest of Sagebrush Flat about 1 mile from the present main road between the Fraser Experimental Forest and the town of Fraser (fig. 3).

The original stands in the area west of the present road south to Sagebrush Flat were mature mixed Engelmann spruce, subalpine fir, and lodgepole pine. They were logged until 1907, when sparks from the logging locomotive set the area on fire. After the fire, the area regenerated to lodgepole pine, and today it is stocked with second-growth lodgepole pine. Railroad logging in the general area continued until about 1912 when the lumber company went bankrupt. By 1918, the mill, railroad, etc., no longer existed. Although the railroad was abandoned and the rails taken up, and the mill dismantled, evidence of the old railroad grade and the concrete footings of the mill site can readily be seen today. The logging engine, a Climax, was left standing on a short stub-end siding at Fraser until 1939 (fig. 4).

To the east of the present main road, the land area in the St. Louis Creek drainage north of the original National Forest boundary was a combination of "school lands" and other private ownership. The original forests in this area also were

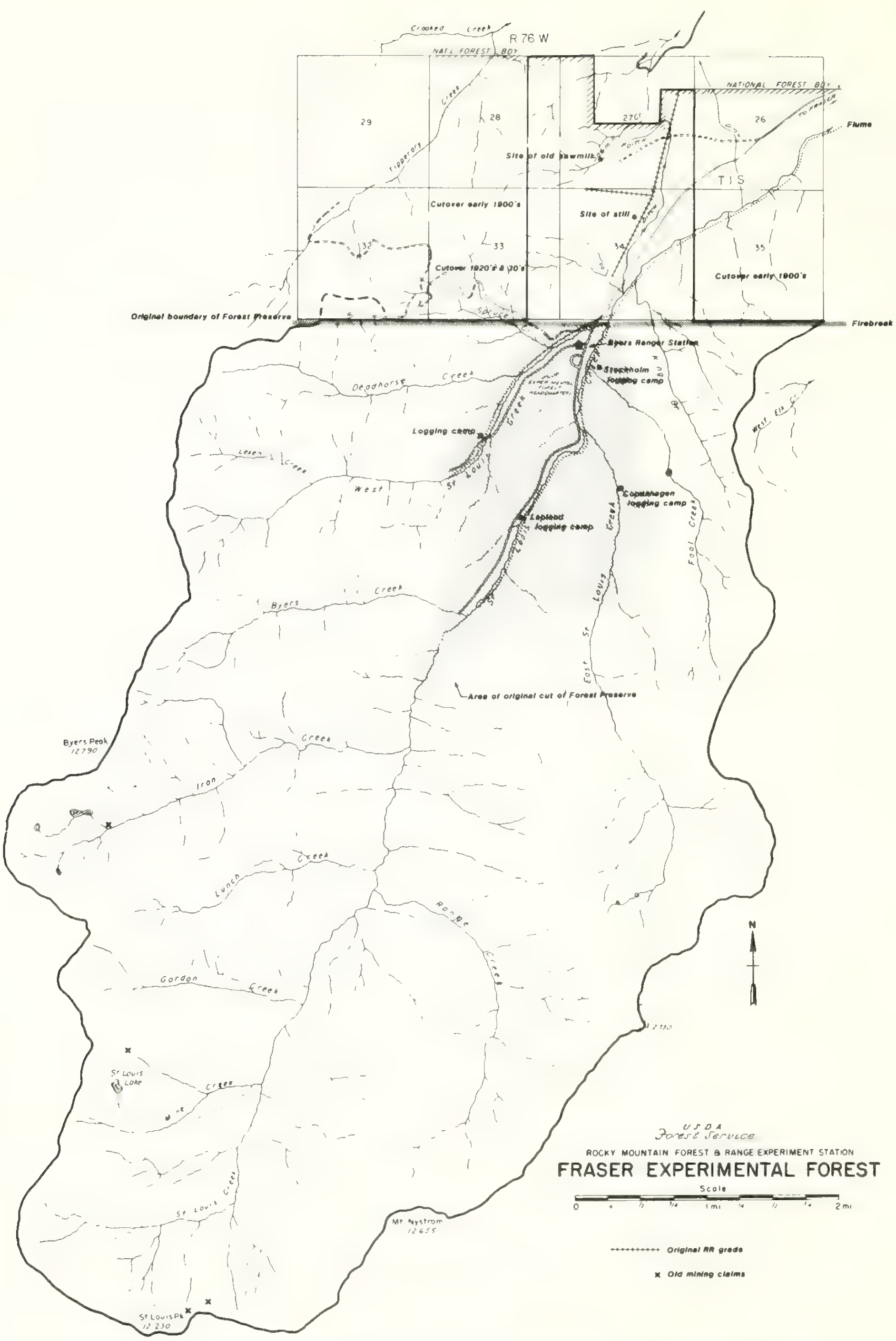

Figure 1.--Diagrammatic sketch of the St. Louis Creek drainage, showing location of streams, roads, physical structures, and mining and logging activity before establishment of the Fraser Experimental Forest.

logged over and burned. These lands regenerated to aspen and lodgepole pine, with the latter now crowding out the aspen.

Concern about the repeated fires in the areas north of the original forest boundary caused the early National Forest officers to cut a 600-foot wide firebreak from ridgetop to ridgetop along the north boundary of the National Forest lands sometime about 1910 (fig. 1). All trees were felled, and the usable material sold and removed. The firebreak, which regenerated to dense, second-growth lodgepole pine, can be identified today.

Most of the cutover and burned over lands below the original forest boundary were acquired by the Forest Service in a series of land exchanges between 1928 and 1930. In 1951, the last cutover private land, now within the boundaries of the

Figure 2. Loading logs at the end of the rail line. Note size of logs on the flatcars (1907).

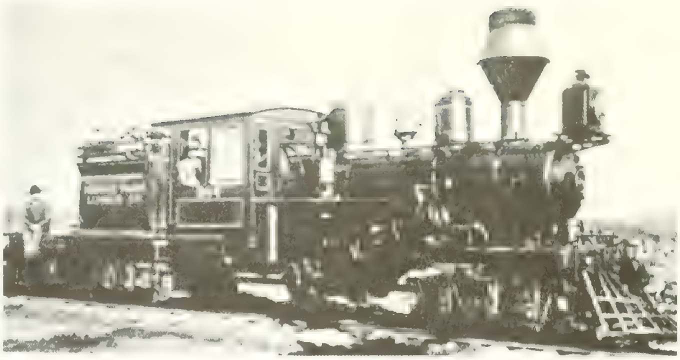

Figure 4.--Climax locomotive No. 684 used to haul log train from woods to the mill (1907).

Fraser Experimental Forest, was obtained from Koppers Co., Inc.

Early timber harvesting on the National Forest also began about 1910. These stands also were mature mixed spruce, fir, and lodgepole pine. Individual trees were marked and cut rather than following the clearcutting practices used on adjoining private lands. The original nails scribed with U.S. and the date used to designate cut trees can still be found in stumps where they were placed after the trees were cut.

During the early timber harvesting on Forest Service land, a flume was built from a mill, located just east of the present Koppers Co. yard and north of the town of Fraser, and extending along St. Louis Creek to just above its confluence with Byers Creek (fig. 5). A flume also was built from the confluence of St. Louis Creek and West St. Louis Creek along the latter stream for a distance of about 2 miles. Evidence of the flume and the structures used to dam water (fig. 6) still can be seen today.

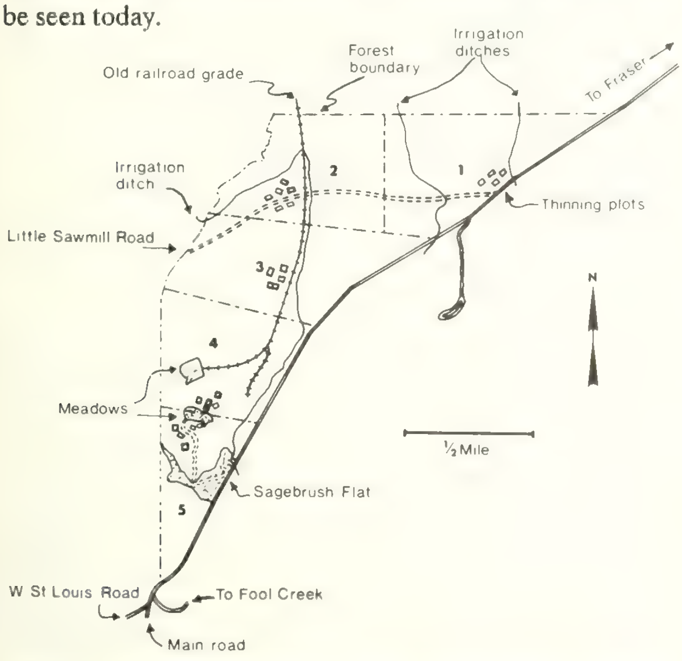

Figure 3.--Diagrammatic sketch of area now occupied by second-growth lodgepole showing location of old railroad grade, irrigation ditches, roads, and research plots. This area originally was in private ownership.

Trees on the National Forest lands generally were in the 11- to 15-inch diameter class (i.e., material suitable for railroad ties). This partial cutting resembled a two-cut shelterwood. In areas near the flume, logs were cut, skidded by horses, and decked at landings along the flume where they could be loaded into the flume for transport to the mill (fig. 7). As cutting progressed away from the flumes, logs were either loaded into horse-drawn wagons for transport to the landings in the summer or into horse-drawn sleds in the winter (fig. 8). Logs decked during the winter were not flumed until water could readily flow through the flume without freezing. Judging from the extensive network of wagon roads still evident on the ground, most of the areas along all stream bottoms within skidding distance of the flume were cutover. During this period of time, some logs also may have been transported to the mill in wagons or sleds.

When logging began on the National Forest, logging camps were established at several locations. The camp at "Lapland" was located in the clearing about 1 mile south of the Fraser Experimental Forest headquarters, where the Denver Water Board's siphon crosses the main road (fig. 9); the camp at "Stockholm" was located in the clearing across St. Louis Creek east of the Experimental Forest headquarters; and the camp at "Copenhagen" was located in a clearing just below the present gaging station on East St. Louis Creek. The largest camp was "Lapland," which provided housing for both single and married loggers (fig. 10). These camps persisted until after World War I, but evidence of their existence has been obliterated, with the exception of the ruins of a cabin, stable, and cookhouse at Copenhagen. In addition, there were other more temporary camps. One of these was located on the site later occupied by the Byers Ranger Station. There are people still living in the Fraser area that were born in these logging camps.

There also is evidence of an old logging camp and two sawmill sets on Spruce Creek about 1 mile west of the present Fraser Experimental Forest headquarters. However, these remnants of early logging activity were in use as late as the 1930s when the land to the west and north of the camp and sawmill sets was in private ownership.

About 1915, the Byers Ranger Station was built in the clearing just north of the present Fraser Experimental Forest


Figure 5.--Wooden flume constructed to transport logs to the mill at Fraser.


Figure 6.--Headgate and dam constructed to provide the head of water needed to float logs in the flume.


Figure 7.--Logs decked near "Lapland" waiting transport to the mill by flume.


Figure 8.--Horse-drawn sled used to transport logs to landings in the winter.


Figure 9.--Logging camp at Lapland, 1917.


Figure 10.--The Frank Madison (left) and J. B. Stevens (right) families at Lapland (1917) ready for church.

headquarters. This station, occupied year long, consisted of a two-story house, barn, and outbuildings constructed from rough logs (fig. 11). The station, occupied until the 1930s, persisted until the 1950s, when all buildings but the log barn were either torn down or moved. The old barn, now used for storage, is the only visible remains of the station. The ranger assigned to this station was responsible for general administration of the area, including the establishment of an extensive system of trails that accessed the largely roadless area within the forest boundary. Today, many of the trails have been abandoned, but there still is evidence on the ground and an occasional trail sign.

As the Forest Service acquired those lands below the original forest boundary beginning in the 1920s, logging activity diminished, with the exception of those lands north of the forest boundary and west of the present main road that were owned by Koppers Co. This reduction was due largely to the fact that most readily accessible land had been cut over and/or burned over, and the market for railroad ties was poor. Logging on Koppers' lands, mostly for poles, continued until they were acquired by the Forest Service in the early 1950s in a land exchange.

Other activities occurred on lands north of the original forest boundary after they were acquired by the Forest Service but before the establishment of the Fraser Experimental Forest. During Prohibition, a still was established west of the present road about half way between the Fraser Experimental Forest headquarters and the present Experimental Forest entry sign (fig. 1). The operators distilled moonshine whiskey and stored it in barrels for resale. A disgruntled competitor or customer notified local law enforcement officers, who destroyed the still. The broken barrels, staves, and hops still are visible, scattered around the site.

Water always has been important to the ranches in the Fraser Valley. Three irrigation ditches transport water from St. Louis Creek west and north to ranchers for irrigation of heavy meadows (fig. 3). Today, all ditches are operational, but water carried by some of the ditches has been sold to the Denver Water Board.

Figure 11.--Byers Ranger Station. Location was just north of present Fraser Experimental Forest headquarters.

Both cattle and sheep allotments in force on the Fraser Experimental Forest predate establishment. The cattle allotment was for 55 AUMs for a number of years, but has been 23 AUMs in recent years. Cows and calves are turned onto the Experimental Forest by the permittee on July 1 and are removed by October 1. The sheep allotment (1,000 to 2,000 head band) is part of a larger allotment. Sheep normally are moved up the Darling Creek driveway, moved across the high county, and end up on the Fraser Experimental Forest before being removed down the Fool Creek driveway. In recent years, the permittee has chosen to take nonuse in 3 out of every 4 years.

After Establishment of the Fraser Experimental Forest

The McSweeny-McNary Act, passed by Congress in 1928, authorized 12 regional forest experiment stations. The Rocky Mountain Forest and Range Experiment Station, the last of the experiment stations funded by the Act, was established July 1, 1935. It is headquartered in Fort Collins, Colo., in cooperation with Colorado State University. Because it was the policy of the Forest Service to concentrate research work on experimental forests, the Rocky Mountain Station, with assistance from the officers of the Regional Forester and Supervisor of the Arapaho National Forest, selected the 23,000 acres of St. Louis Creek drainage as an area for research. On May 10, 1937, the report establishing the Fraser Experimental Forest was submitted, and on August 26, 1937, it was approved by the Chief of the Forest Service. Original efforts were concentrated on timber and watershed research. In later years, the scope of research activities on the Fraser Experimental Forest has been significantly expanded.

The objectives and results of studies conducted on the Fraser Experimental Forest are beyond the scope of this narrative. This information has been documented by Alexander and others in numerous publications listed under Research Published 1937-1985 of Alexander et al. (1985).[2]

The area set aside for research originally was called the St. Louis Creek Experimental Forest, but the name was changed to Fraser Experimental Forest before formal establishment. While the Experimental Forest is part of the Arapaho National Forest, it is administered by the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. The present Fraser Experimental Forest occupies all of the original Forest Reserve and lands west of the main road, and north along the road to the Arapaho National Forest boundary (fig. 12).

The first research personnel assigned to the Fraser Experimental Forest established a tent camp in 1937 on Byers Creek, just south of where it enters St. Louis Creek (fig. 13). The

[2]Alexander, Robert R.; Troendle, Charles A.; Kaufmann, Merrill R.; Shepperd, Wayne D.; Crouch, Glenn L.; Watkins, Ross K. 1985. The Fraser Experimental Forest, Colorado: research program and published research 1937-1985. Gen. Tech. Rep. RM-118. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 46 p.

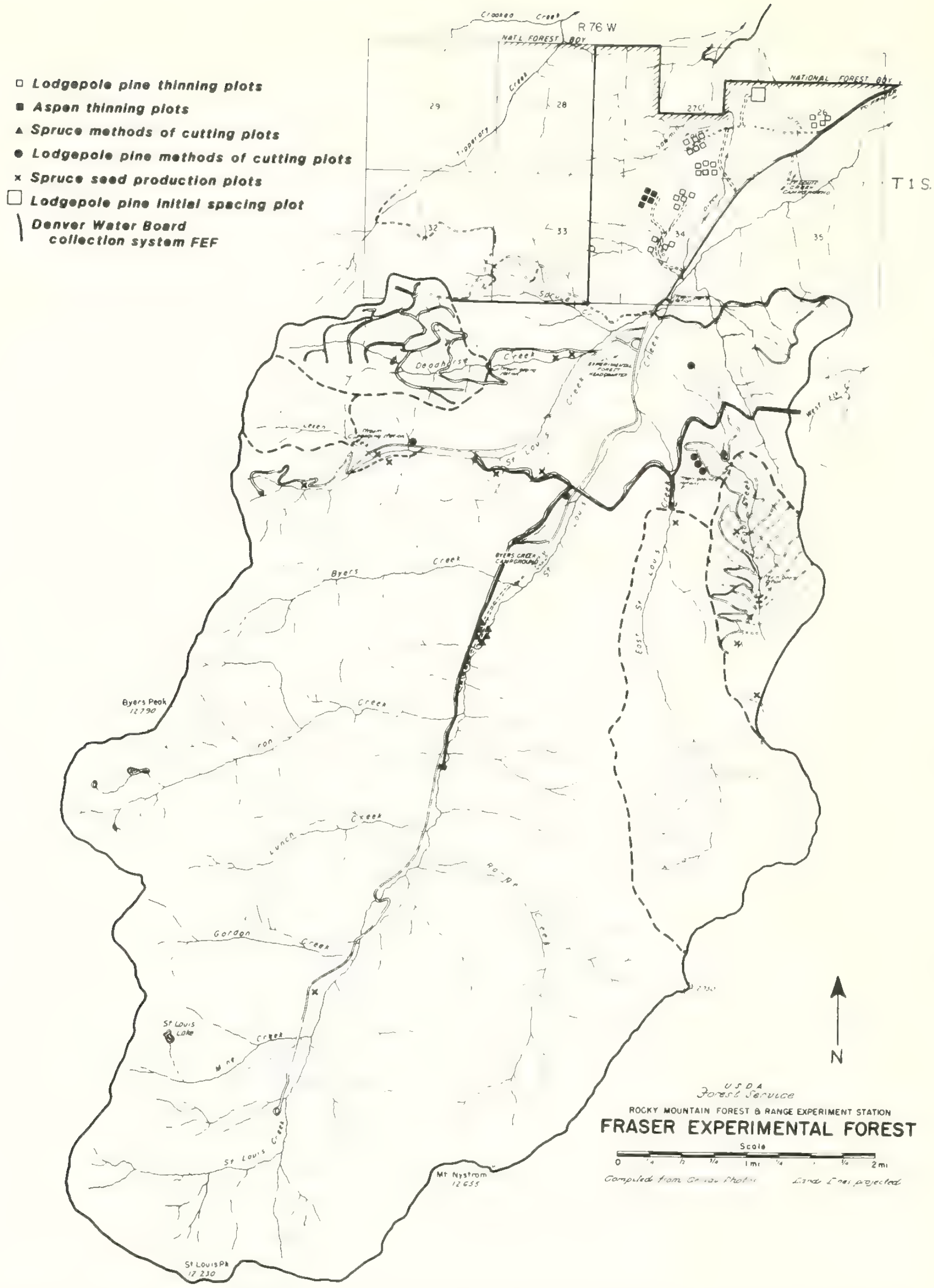

Figure 12.--Diagrammatic sketch of the Fraser Experimental Forest as it exists today showing locations of streams, roads, water diversions, other physical structures, and research plots.

original survey crew was primarily responsible for cruising and mapping early study areas, but they also staked and cleared the site for the present headquarters and cut and peeled the first logs hauled to the site for construction of the buildings.

In 1938, a CCC camp was established on the present site of the Fraser Experimental Forest headquarters. It consisted of barracks, a cookhouse, recreation hall, lavatory, and numerous storage and service buildings. Enrollees at this camp were responsible for cutting and milling most of the logs used to construct the two-bedroom house, the two single-bedroom houses, and the log garage that are still part of the headquarters complex (fig. 14). The buildings were constructed between 1938 and 1940 by local skilled artisans (carpenters, brick layers, etc.) employed by the Economic Recovery Administration (ERA). Original plans called for additional housing and storage buildings, but with the advent of World War II, the camp and the CCC and ERA programs were dissolved.

The original access to the headquarters area was a single lane road from the town of Fraser that paralleled the current road. This old road was frequently impassable during wet weather. The present all-weather two lane road was constructed in 1946-47 by the Public Highway Department.

After the CCC camp closed, one barrack, the cookhouse, recreation hall, and lavatory were retained for use by temporary summer field assistants hired to assist scientists in their work. The recreation hall collapsed in the late 1940s, and the

Figure 13.--Tents were used to house research personnel before construction of permanent housing at Fraser Experimental Forest headquarters. This tent was located at the Byers Creek site.

Figure 14.--Areal view of headquarters complex, Fraser Experimental Forest.

barrack, cookhouse, and lavatory were either demolished or moved in 1956, when the present dormitory and lounge were built. The office building was obtained from the Bureau of Reclamation in 1952 and located at its present site. Log siding was added to the frame building to blend in with the other log buildings. The metal garage in the work area was erected in the early 1960s, the log records storage building, originally a survival cabin, was moved from its site south of the old Fool Creek gaging station and placed at its present location in 1984, and the cookhouse and laboratory buildings were prefabricated and located on site in 1985 and 1986, respectively.

One of the original research efforts on the Fraser Experimental Forest was to locate and inventory the lodgepole pine methods-of-cutting plots on King Creek. These plots, consisting of five cutting treatments replicated four times, occupied 160 acres (fig. 15). Plots were harvested by ERA crews in 1939-1940. Trees were cut and the logs skidded by either horses (fig. 16) or tractors (fig. 17) to landings. Logs then were either transported by trucks to a local mill in Winter Park or milled on site by ERA crews with a portable sawmill (fig. 18). Access to these plots was provided by the King Creek Loop road, which was reconstructed in the late 1940s to its current standard.

A number of the original lodgepole pine methods-of-cutting plots in Block C along the upper loop of the King Creek road were obliterated in the early 1980s, when three large, 10- to 30-acre, clearcut units were installed to measure the effects of snow deposition in large openings (fig. 19).

In the early 1940s, the West St. Louis Creek road was constructed to the first switchback below the present access road to the Lexen Creek gaging station. This road originally was built to access Block I of the spruce-fir methods of cutting study. Block I, consisting of three treatments (fig. 20) and

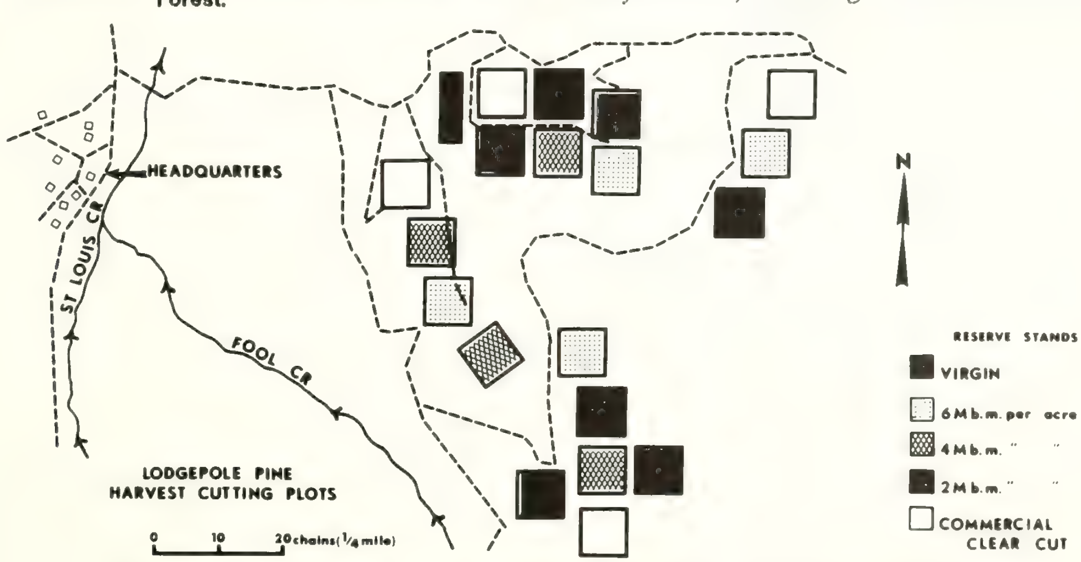

Figure 15.--Diagrammatic sketch of the location of the original lodgepole pine methods of cutting study on King Creek.

Figure 16.--Skidding logs with a horse on the lodgepole pine methods of cutting plots on King Creek in 1939.

Figure 17.--Tractor used to skid logs on the lodgepole pine methods of cutting plots on King Creek in 1939.

Figure 18.--Portable sawmill used to mill logs on site on the lodgepole pine methods of cutting plots.

Figure 19.--Large clearcut unit on the Fraser Experimental Forest cut to measure effects of snow deposition in large openings.

Figure 20.--(A) two-step shelterwood, (B) group selection, and (C) alternate strip clearcutting, Fraser Experimental Forest.

uncut control occupying 24 acres, was cut in 1944 by POWs from a camp established near the town of Fraser. The POWs employed were mostly Bavarians from Rommel's Africa Corps, who had considerable woods experience. The logs were bought by and transported to the mill in Winter Park. Construction of the West St. Louis Creek road, including the loop, was completed in the early 1950s. This road originally was intended to provide access to Blocks II and III of the spruce-fir methods of cutting study. However, the blocks were never cut. Today, the road provides part of the access to the Byers Peak and Bottle Pass trails.

The first watershed study on the Fraser Experimental Forest involved the paired Fool Creek and East St. Louis Creek watersheds. The treated watershed (Fool Creek), a 714-acre drainage, has been gaged since 1940. The original streamgage was replaced in 1980. The streamgage on the control watershed (East St. Louis Creek), a 2,198-acre drainage, originally was constructed in 1942 and reconstructed in 1965. The original access road to the Fool Creek streamgage was built in 1940 and reconstructed in the late 1940s. The current Fool Creek road system, 4.5 miles of main road and 8 miles of spur roads, was constructed in the early 1950s (fig. 12). Today, only the main road is maintained. Fool Creek was harvested in 1954-56 by removing timber in alternate cut and leave strips that varied from 66 to 400 feet in width (fig. 21). Logs were skidded with horses, decked, and saleable material hauled by truck to the Koppers Co. mill yard in Fraser. Unsaleable pulpwood products were decked in a clearing near the first switchback above the gaging station on the main road. This material was sold later as firewood to local motel and condominium operators.

In 1955-56, streamgages were constructed on another pair of watersheds on the west side of Fraser Experimental Forest. The treated watershed (Deadhorse Creek) is a 667-acre drainage; the control watershed (Lexen Creek) is 306 acres in size. The access road from the West St. Louis Creek road to the Deadhorse Creek main streamgage was built in 1955 and that to the Lexen Creek gaging station in 1956. The remaining access roads into Deadhorse Creek (approximately 9 miles of main and spur roads) were constructed from the early 1970s to the early 1980s (fig. 12). Two additional streamgages were built in the early 1970s, one on the North Fork and one on the Upper Basin. The first timber harvesting on Deadhorse Creek was in 1977-78, when the 100-acre North Fork unit was harvested by clearcutting about one-third of the subdrainage in small 3-acre clearcut patches. The North Slope unit, another 100-acre subdrainage, was harvested in 1980-81, when about one-third of the volume was removed in the first cut of a three-step shelterwood. The last unit harvested was the Upper Basin, a 200-acre subdrainage, where about 30% of the area was harvested in 1982-84 in small 1- to 5-acre clearcut patches (fig. 22). In all of these units, logs were skidded downhill to landings using rubber-tired skidders and small crawler tractors. Logs were hauled by truck to the mill in Fraser.

In 1955, the Denver Water Board constructed its water collection system on the Fraser Experimental Forest. Water, collected from all streams except Deadhorse and Spruce Creeks, is diverted by a series of gated structures into a collection system consisting of buried concrete and steel pipes varying in diameter up to 6 feet. Water is transported through this system into a 1,700-foot tunnel on King Creek and into the Vasquez Creek collection system for eventual transport through the Moffet Tunnel. Part of the present Fraser Experimental Forest road system is constructed over the Denver Water Board Diversion system (fig. 12).

A skyline cable system for logging steep slopes was tested from 1956 to 1959 on the Fraser Experimental Forest (fig. 23). The site was located on West St. Louis Creek, and the cableways from the three settings used are still visible to the west from the road just above the turnoff to the Lexen Creek gaging station (fig. 24). Trees were removed from slopes of 25% to 80%, a distance of one-half mile from the main landing, by both clearcutting and partial cutting.

In the early days, the Fraser Experimental Forest was considered a "back country station," and the Forest employed a cook during the summer months. From 1945 through 1960, when the government mess was discontinued, the cook was Andrew J. O'Malia. A sign "Ike Ate Here" hangs over the entrance to the dining room of the "lodge" at the Fraser Experimental Forest. President Dwight D. Eisenhower was a guest at the Byers Peak Ranch at Fraser, Colo., for part of the summers of 1953, 1954, and 1955. The Experimental Forest joins the west boundary of the ranch.

During the summer of 1953, arrangements were made with Sherman Adams (formerly a lumberman), Special Assistant to President Eisenhower, for the President to visit and have lunch

Figure 21.--Paired Fool Creek and East St. Louis Creek watersheds after strip cutting on Fool Creek was completed in 1956.

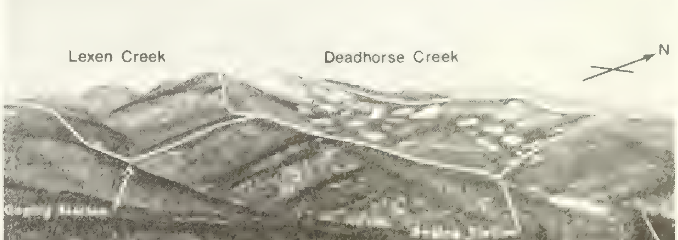

Figure 22.--Paired Deadhorse and Lexen Creek watersheds after timber harvesting on Deadhorse Creek was completed in 1984.

Figure 23.--Turn of logs being transported to the landing by skyline cable system, 1956.

at the Experimental Forest. President Eisenhower also was considered to be a good "camp cook." He and Andy became friends, and that lead to Eisenhower's introduction to then-Chief Dick McArdle at the dedication of the Missoula, Mont. fire lab in 1954.

Figure 24.--Cable logging site after system was removed showing cableways and timber harvesting patterns.

In the 50 years since the establishment of the Fraser Experimental Forest, about 50 scientists and a dozen technicians, permanent staff, and support personnel at Rocky Mountain Station, have been assigned to work on the Forest. (They are listed at the end of this paper.) In addition, nearly 100 scientists have worked there as either summer field assistants or as graduate students. During this time, more than 240 publications, Ph.D dissertations, and Masters theses have been produced from research done on the Forest (Alexander et al. 1985). Moreover, scientists from all over the United States and many foreign countries have visited the Fraser Experimental Forest to learn about research accomplished and underway.

In recent years, new areas on the Fraser Experimental Forest have been cut and thinned for studies (fig. 25) and demonstrations (fig. 26) that are part of the current research program. These activities and other studies underway are documented in papers presented in this symposium and in numerous publications listed by Alexander et al. (1985).[2]

Figure 25.--Young lodgepole pine thinned to GSL 120, Fraser Experimental Forest.

Figure 26.--Three-cut shelterwood demonstration area in old-growth spruce-fir, Fraser Experimental Forest.

Appendix1.--Personnel at the Fraser Experimental Forest.

Hydrology and soils	Timber	Wildlife and forest pests	Technician	Cook	Original survey crew
Jim Bergen	Bob Alexander[1,2]	Glenn Crouch[2]	Walt Florquist	Andy O'Malia	Kliess Brown
M. H.Collett	Ray Boyd	Frank Hawksworth[2]	Roy Hanson[3]		Dwight Hester
Harry Brown	Carl Edminster[2]	John Schmid[2]	Roger Kerbs[3]		Lee Ross
Charles Connaughton	Francis Herman	Charley Wallmo	Manuel Martinez[2,3]		Ralph Read
Willie Curtis	Bill Hornibrook		Steve Mata[2]		"Steve" Stevens
Jerry Dunford[1]	John Jones		Don Moore		Hugo Werner (Chief of Party)
Ernie Frank	Ed Kotok		Stu Parks[3]		
Howard Gary	Bert Lexen[1]		Don Reichert[2]		
Bert Goodell[1]	Sue McElderry		Slim Smith		
Arden Haeffner	Todd Mowrer[2]		Dan Taussig		
Burchard Heede	Dan Noble		Ross Watkins[2]		
Marvin Hoover[1]	Frank Ronco		George Wheatley[3]		
Paul Ingebo	Wayne Shepperd[2]				
Merrill Kaufmann[2]	Joye Smith				
Chuck Leaf[1]	Rudy Stahelin				
Grenville Lloyd	Ray Taylor[1]				
Dud Love[1]					
Pete Martinelli					
Jim Meiman[2]					
C. H. Niederhof					
John Retzer[1]					
Bob Swanson					
Butch Skow					
Jess Thompson					
Chuck Troendle[2]					
Hal Wilm[1]					

[1]At one time, responsible for overall management and research direction of FEF.

[2]Active 1987.

[3]Technician in charge of operations.

The Role of Experimental Forests in Forestry Research

John M. Ohman, Charles M. Loveless, Richard G. Cline, and M. Dean Knighton[1]

When the pioneers reached Ohio in their march to settle the interior, they found a hardwood forest so dense that it is said a squirrel could scramble through the treetops all the way from Lake Erie to the Ohio River. Clearing that land for agriculture was a monumental task, but one made more palatable by the growing Nation's demand for timber. In the early years of our country, the wood supply must have appeared limitless. But by 1831, the fledgling Federal Government acknowledged that was not the case: Congress passed a law specifying punishment for cutting, destroying, or removing live-oak and other timber or trees. But passage of this legislation demonstrates that America's politicians recognized our timber resources were finite.

By the end of the Civil War, the prospect of a timber famine--or at the very least, a shortfall in meeting America's expansionist appetite for wood and wood products--provoked Congress into action once again. A rider attached to the 1876 general appropriations act designated that $2,000 be used to investigate, among other things, the wood-supply outlook for the future, the best means for preservation and renewal of the Nation's forests, and the effects that forests have on climate. USDA's Division of Forestry was formed in 1886, and this organization, in turn, was the precursor of the Research Branch of the Forest Service.

Under the direction of division chief B. E. Fernow, a professional forester, the original "investigations" became more technical and broadened in scope to involve extension activities--possibly America's first technology transfer effort!

Gifford Pinchot took over the division in 1898. The forest reserves, which had been set up in the Department of the Interior, were transferred to the Department of Agriculture in 1905. This event marked the birth of the Forest Service.

Many researchers worked directly for national forest administrators during this period. Though studies were designed and sample plots established, research was often begun without much advance planning. Changing personnel and the lack of adequate supervision resulted in the accumulation of incomplete data and regular loss of records. Agency priorities emphasized efforts to administer the large areas of land contained in the forest reserves (called national forests after 1907). Research was essentially subordinated to the demands of National Forest administration.

The consolidation of all Forest Service research activities in a Branch of Research, under the Chief Forester's coordination in 1915, marked a turning point toward better planning and improved quality control.

Creating the First Experimental Areas

Franklin Hough's final report in 1882 suggested that land areas specifically devoted to forestry research be set aside exclusively for that purpose. The first evaluation of such an area--the Santa Rita Reserve, just outside Tucson, Arizona--was completed in 1902. A presidential executive order allocated this area to range research in 1910, adding it to the agricultural experiment station established there a decade earlier.

The first forest experiment station, in Fort Valley, Arizona, was established in 1908. It was followed soon after by the Fremont, in Colorado, in 1909.

During this period, the classic Wagon Wheel Gap watershed study was initiated and handled as a branch of the Fremont Station. This was the only study of its kind in America, and paralleled only one other such effort, in Emmenthal, Switzerland. The lessons learned at Wagon Wheel Gap enabled scientists to refine their understanding of the techniques required for long-term watershed research

The Nation's First Experimental Forests

While America struggled through the Great Depression, Forest Service research expanded greatly. Though we had been doing research since the earliest days of the century, it was not until the McSweeney-McNary Act of 1928 that a separate research arm of the Forest Service was officially

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sanctioned. Economic conditions restricted the amount of money available, but Civilian Conservation Corps and Works Progress Administration enrollees provided the labor to expand our physical plant greatly.

The first experimental forest was officially designated on January 21, 1931. Appropriately, it was the Fort Valley Experimental Forest, site of the first forest experiment station. Of the 113 experimental forests eventually set aside, 39 were established during the thirties.

Experimental Forests Between 1930 and 1980

Increasing concern about the Dust Bowl during the thirties led to the establishment of several research watersheds now considered invaluable for their long-term records. The most notable of these were Coweeta, in North Carolina (53 years of record), Davis County, Utah (51 years of record), and San Dimas, California (49 years of record). This conference celebrates the 50th anniversary of the Fraser Experimental Forest, established in 1937 here in Colorado.

The decades of the forties and fifties saw additional experimental forests incorporated into the system, but at a much slower pace. Budget constraints and the need for site-specific research programs limited the system's rate of expansion. The environmental awareness of the 1960's resulted in another flush of experimental-forest establishments. But, interestingly, this period saw the deletion of 16 experimental forests.

Where Do the Experimental Forests Stand Now?

Experimental forests started out as independent local centers of research. They evolved into a network of areas of land dedicated to accomplishing the research objectives of the more regionally oriented forest and range experiment stations. These areas continue to be a valuable resource in our search to understand complex forest ecosystems. But the primary value of experimental forests is their availability for long-term experimental studies. They also serve as representative ecosystems from which research results can be extrapolated or compared with other geographic areas.

Long-term research records are absolutely essential in studying hydrologic cycles and the factors affecting those cycles. It takes at least 4 years--often more--to adequately calibrate a watershed. And this must be done prior to beginning experimental treatments.

The value of long-term records in silvics and other aspects of forest-management research is also obvious, given the length of the life cycle of most trees and the associated rotation length of forest stands.

Experimental forests have provided us with a place to do long-term studies without worrying about our ability to complete them because of conflicting activities (such as the need to cut timber or show a profit). Our understanding of the effects of timber management and the functioning of ecosystems has been greatly enhanced through studies on experimental forests. Long-term silvicultural studies there have produced both local and basic information directly connected to improvements in forestry practices. Typically, these studies have focused on stocking, thinning, growth and yield, and regeneration.

Experimental forests are intentionally located to be representative of the range of environments encountered on lands managed by the Forest Service. The Fraser Experimental Forest, for example, features conditions typical of a high-elevation subalpine environment.

Long-term silvicultural studies are frequently well suited to wildlife investigations, a subject of increasing interest to the Forest Service. Wildlife habitat changes because of changing conditions as forest stands grow and mature. Habitat alterations bring about sharp differences in wildlife species composition. This phenomenon was observed at the Fraser Experimental Forest in research associated with studies of timber-management practices.

Emphasizing Watershed Research

Watershed research is another area that benefits greatly from its association with experimental forests. It demands long-term data sets, both for calibration and for comparison. A few watershed studies were begun at the early forest experiment stations, and permanent watershed studies were developed at several experimental forests during the expansion period of the 1930's. The data sets established over the intervening years are considered treasured assets at these locations, forming the background against which current studies can be evaluated.

Relatively few experimental forests enjoy a continuous history of watershed data approaching 50 years. To some, emphasizing the length of continuous watershed data might sound like a numbers game. It is not. Year-to-year climatic variability makes it difficult to draw conclusions from short-term (several-year) data. It is progressively easier, and sounder, to draw conclusions as reference data sets encompass longer time periods. Therefore, watersheds with this asset are especially valuable.

New Concerns

As time passes and new issues emerge, we need different kinds of data from our research watersheds. Human health concerns have demanded that we pay more attention to the chemistry of stream and soil water. Concern for forest growth has brought about the current push to investigate nutrient cycling and sources of nutrient supply. Recently, data sets

dealing with nutrient chemistry have served an important additional function as sources of background information in acid deposition studies. While data from nutrient studies do not completely satisfy the demands of acid deposition researchers, this information and its continuity with other background data are particularly valuable.

If Forest Service research is to push forward in profitable new directions, we need to reexamine the areas of prior research that have benefited us the most. Certainly one of these is the development and maintenance of our system of experimental forests. They have provided us a place where we can exercise adequate control over our research operations without the fear of losing the fruit of our efforts after obtaining only part of the desired data. They have fostered an invaluable long-term data base that promises to become more important in the future.

Data on forest stands frequently do not encompass even one full rotation. Our data base for stands rounding out their rotations cannot help but become more complete and instructive thanks to the work done on experimental forests.

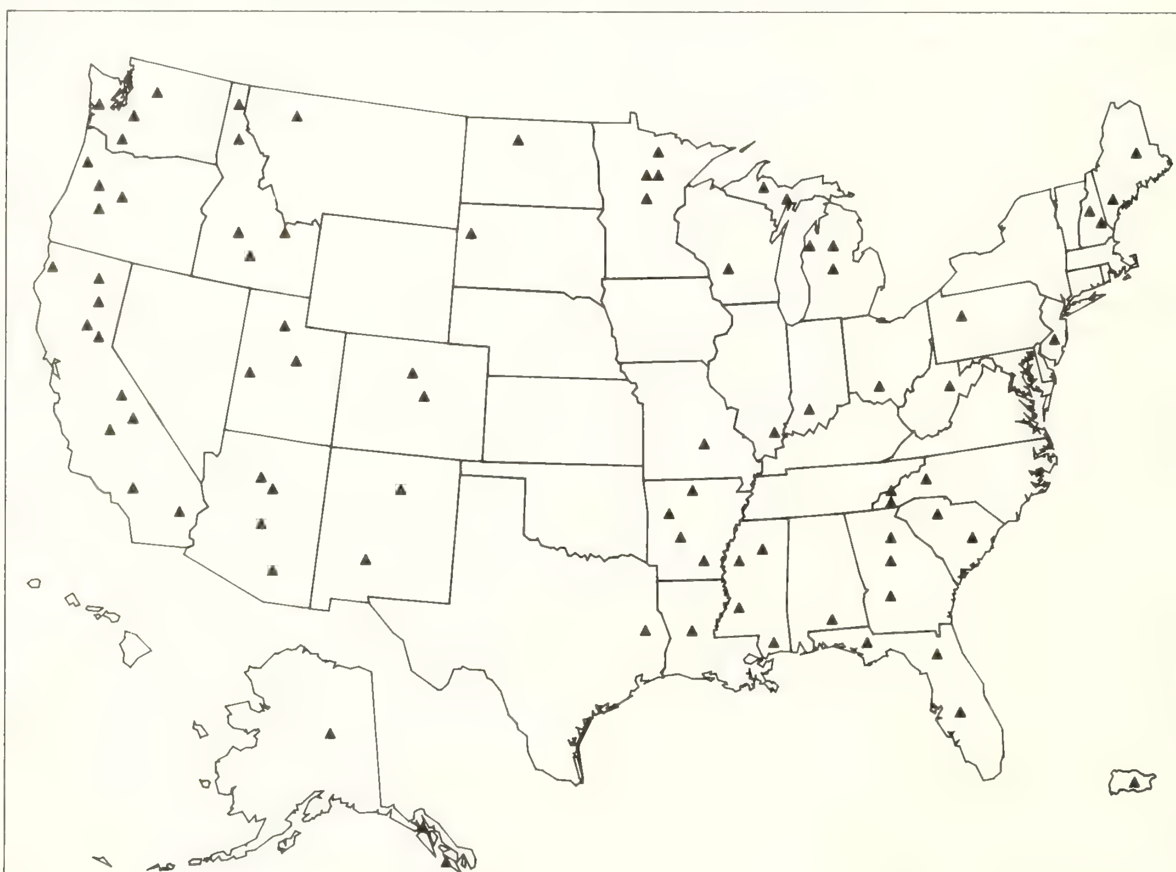
These forests have more value as a system than any single location or data set can provide. The accumulation of data over long periods of time and wide geographic areas has great potential. Our participation in the Man and the Biosphere and Long-Term Ecological Research programs is evidence of the Forest Service's commitment to the long haul. We need a system of diverse locations to achieve our research goals.

The experimental forests are furnishing large amounts of data at an astonishing rate, but the information contained in these data cannot be used until people know about it. Our challenge is to analyze and publish our results so what we have learned can be used. This is no small task. We are further challenged to make the geographic comparisons that the data accumulated from the various parts of our experimental forest system can support. Drawing conclusions from this imposing data set is a uniquely fascinating prospect and a monumental job.

Our experimental forests are in a state of flux both in terms of their numbers and the kind of work being done there. This is a healthy situation because it means we are thinking about our objectives and making decisions to direct our course.

The future will undoubtedly bring us similar challenges and changes. Our long-term records contain information that will help us attack emerging problems in areas such as cumulative effects, global climate, and forest health. Often, however, records are not complete. In places where our watershed records cover more than 50 years, we may have water chemistry data from only half this period. Some of the chemistry important in evaluating acid rain has been collected for only 8 to 10 years.

Our task is to take positive action to meet future challenges, build upon the knowledge of the past, and make the critical decisions to assure our experimental forests are as useful as possible in the future.



Silvicultural Research in Coniferous Subalpine Forests of the Central Rocky Mountains

Frederick W. Smith[1]

Abstract--Silvicultural research in the central Rocky Mountains has been influenced by the high proportion of old-growth forests, poor markets, modest growth rates and emphasis on resources other than wood production. Four areas of research have been stressed in the region classification, natural regeneration, reproduction methods and density control. As a result, silvicultural prescriptions can be tailored for specific site and stand conditions to achieve a variety of resource objectives.

Silvicultural problems and research in the subalpine zone of the central Rockies are related to the unique climate and forest uses in this region. The zone, which extends from 9,000 to 11,00 feet is characterized by short growing seasons, low temperatures and high radiation (Peet 1981). Tree species in the zone are limited in number. Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Engelmann spruce (*Picea englemannii* Parry ex. Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) dominate the coniferous subalpine forests, with aspen (*Populus tremuloides* Michx.) as a common deciduous associate. Productivity is low to moderate (20 to 120 $ft^3a^1y^1$) (Green and Van Hooser 1983) and regeneration can be difficult. Steep environmental gradients, largely a function of elevation, topography and soils, result in large local variation among sites. A high proportion of existing stands are unmanaged, are relatively old and may be of low vigor. Markets for wood products are poorly developed and stumpage prices are low (Long et al. 1986). Production for consumptive use, especially on public land, often emphasizes water, grazing or wildlife over wood products. Non consumptive uses, whether recreation or preservation, are important determinants of management goals throughout the region.

Silvicultural practices are commonly less intense than in other regions and management to enhance wood production is often subordinate to producing stands to meet other resource goals. Regenerating older stands is the major task facing silviculturists in the region. With low to moderate productivity and poor markets, natural regeneration is the dominant regeneration technique. Therefore, research has emphasized reproduction methods and other techniques to secure suitable natural regeneration. Intermediate operations, mainly thinning, are used to control density, spacing and composition of naturally regenerated stands.

I will review four areas of research in subalpine forests of the central Rocky Mountains dominated by Engelmann spruce and subalpine fir, or lodgepole pine classification, natural regeneration, reproduction methods and density control. These areas are of the most interest to silviculturists and have been emphasized in research programs on the Fraser Experimental Forest and throughout the region.

Classification

Classification schemes used in the Region meet two needs indexing productivity and delineating vegetative associations. Site index curves are available for Engelmann spruce (Alexander 1967) and lodgepole pine (Alexander et al. 1967). In conjunction with growth and yield simulators, they provide a means to estimate site productivity under a variety of density management regimes (Alexander and Edminster 1980, 1981). Lodgepole pine is one of the few species where dominant height is known to be reduced at high densities. Therefore, corrections factors have been developed to adjust site index estimates for density related height reduction of site trees (Alexander et al. 1967).

Habitat typing is a vegetative classification system which has recently come into wide use in the central Rockies. Methods for typing large geographic areas have been standardized (Pfister and Arno 1980), and habitat types have been

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developed for most National Forests in the region (e.g. Hoffman and Alexander 1976, 1980, 1983, Steele et al. 1983, Hess and Alexander 1986). Habitat types are defined as the land area which supports or will come to support a given climax community or plant association, and are named for the dominant or indicator species of the overstory and understory unions. Where climax vegetation does not occur, the habitat type can be identified from keys based on occurrence and abundance of seral species. A successional pattern for overstory and understory vegetation and response of different successional stages to disturbance are usually described for each habitat type.

Habitat types provide useful information for prescribing silvicultural treatments. Reproduction methods can be tailored to the pattern of ecological behavior (e.g. tolerance or successional status) of a species in specific habitat types. Regeneration problems, such as release of aggressive competing understory species, can be predicted. From descriptions of the understory union, forage production and palatability can be estimated for domestic grazing or wildlife habitat requirements.

Regeneration

Natural regeneration is the primary technique applied in the region and artificial regeneration is used only under extreme circumstances where natural regeneration has failed or is likely to fail. Successful natural regeneration depends on the provision of a sufficient supply of sound seed, and favorable conditions for germination and early survival. Successful regeneration prescriptions, especially in the relatively harsh environments common to the subalpine zone, depend on a knowledge of these relations (Alexander and Shepperd 1984, Alexander et al. 1984).

Natural regeneration of Engelmann spruce appears to be dependent on high seed production and favorable microsites. Spruce seed production may be higher and more regular than previously thought. In a 15-year study of production rates, good to excellent seed years (> 100,000 seeds per acre) occurred in 7 out of 15 years, but production varied by location and year (Alexander et al. 1986). On a stand basis, seed production was correlated with the basal area of dominant and codominant spruces. In clearcut openings, germination and survival were related to aspect and microsite. On north-facing slopes with scarified and shaded seedbeds, 25,600 sound seeds per acre were required to produce 800 5-year-old seedlings per acre (Alexander 1984). On south-facing slopes, germination and survival were poor even with the most favorable seedbed conditions (Noble and Alexander 1977, Alexander 1984). Clearcut openings that can be successfully stocked on north aspects are limited to 300 to 450 feet wide where seedbeds are scarified and shaded and 200 to 350 feet where seedbeds are scarified or shaded (Alexander 1986b). Survival is so poor on north slopes with unfavorable seedbeds and on south-facing slopes that natural regeneration of clearcut openings is not a viable option.

Regeneration of lodgepole pine requires completely different silvicultural considerations. Lodgepole pine is an aggressive pioneer and an excess of regeneration may be more common than a regeneration failure. Where serotinous cones are present, any harvesting technique which leaves the cone bearing slash distributed through the opening will provide an adequate source of seed. Regeneration in excess of 100 thousand seedlings per acre can occur following natural disturbance or harvest (Clements 1910). Where cones are predominantly nonserotinous, seed dispersal distances must be accounted for when designing openings. Mechanical scarification or broadcast burning improve microsite conditions by limiting temperature extremes and improving soil moisture availability in relation to a duff surface (Hungerford 1980, Lotan and Perry 1983). Reproduction methods and treatment of the cone-bearing slash may be modified to reduce the amount of seed available to produce lower numbers of seedlings.

Reproduction Methods

All of the high forest reproduction methods except the seed tree method are applicable to regenerate Engelmann spruce stands. Choice of an appropriate method depends on the pattern of ecological behavior of spruce in a particular stand and the management objectives for the stand. Some form of partial cutting may be required where spruce regeneration is difficult to achieve in openings, or where management objectives dictate maintenance of a mature forest canopy for an extended period.

Clearcutting in spruce is most commonly used in conjunction with natural regeneration. In the open environment of a clearcut, successful natural regeneration is more likely on a north- or east-facing slope than a south- or west-facing slope (Alexander 1984, Alexander 1986a). Size and shape of clearcuts in spruce are limited to distances that will provide adequate seed dissemination throughout the cut area. Provision of bare mineral soil seedbeds and shade for regeneration are important considerations for success in clearcuts (Alexander 1986a).

Size, shape and orientation of clearcuts are influenced by a variety of forest management objectives, especially enhancement of water yield. Water yields from spruce-fir stands can be increased by patch clearcutting. Optimum increases occur where 30% to 40% of the area within a watershed is harvested in small, 3- to 5-acre openings dispersed over the entire area (Leaf 1975, Leaf and Alexander 1975, Troendle and Leaf 1981, Troendle 1982, 1983). Differences in canopy height causes snow to be accumulated in these openings, which, in turn, increases stream flows at snowmelt in the spring. These effects decline with time as canopy height differences between an opening and the surrounding stand disappear and as

transpiration increases with accumulation of canopy leaf area. On north-facing slopes, shelterwood can be as effective as clearcutting for increasing water yield. Interception and consumptive water use are decreased while evaporation is less than in a clearcut opening (Troendle and Meiman 1984).

Patch clearcutting in successive entries is complicated by the slow height growth of Engelmann spruce. Spruce may require 20 to 40 years to reach breast height, and height of dominant trees at a total age of 60 years (breast height age 30) on SI100 80 may only be 33 feet (Herring and McMinn 1980, Alexander 1986a). Long cutting cycles are required to restrict the size of contiguous openings and to obtain stand heights necessary for adequate seed dispersal.

Partial cutting for even-aged management can be achieved with uniform or group shelterwood. A shelterwood can be applied across a wide range of site conditions but may be necessary to achieve even-aged natural regeneration on south- or east-facing slopes (Alexander 1986a). Shelterwood is used to promote natural regeneration by ameliorating site environmental conditions and providing a seed source. Also, shelterwood may be used to extend the period during which a stand meets other resource objectives by maintaining a partial mature forest canopy until regeneration is established.

Guidelines for uniform shelterwood cutting have been developed for old-growth spruce-fir stands based on stand structure, windthrow hazard and advanced regeneration, (Alexander 1986a). For single-storied stands with low windthrow risk, a three step shelterwood including a light preparatory cutting, an establishment cutting, and one or more removal cuttings after adequate restocking is recommended. For stands with higher risk for windthrow, several preparatory cuttings may be necessary to provide a windfirm stand for the establishment cutting. For stands with two or more canopy stories without a manageable understory on low windthrow risk sites, the upper story may be windfirm, and the preparatory cuttings may be unnecessary. An overstory density of 40% to 60% of the original stand basal area is recommended following the establishment cutting.

The removal cutting of a uniform shelterwood (simulated shelterwood) may be applied where sufficient advanced reproduction is present as a product of natural stand development or inadvertent response to previous cutting (Alexander 1986a). Where advanced reproduction is present, uncertainty in achieving regeneration of harsh sites can be reduced, and rotation age can be shortened. However, advanced regeneration must be of sufficient quantity, quality, species composition and uniformity in spacing to constitute a well-stocked stand. Estimates of damage to reproduction during harvest should be deducted from pre-harvest stocking to assess the adequacy of the understory for management. Pre- and post-harvest stocking evaluations and design of logging operations to control damage to reproduction are recommended.

Group shelterwood may be appropriate where mature stand structures are clumpy (Alexander 1986a). Openings less than two tree heights in diameter are cut to take advantage of the natural distribution of clumps in a stand. A stand can be regenerated in three entries by removing about 30% of the original basal area over about 1/3 of the stand area in each entry. Second and third entries can be made only after openings created in the previous entry are adequately restocked. Openings created in the final entry may require alternative means of regeneration. Openings from the final entry can be artificially regenerated, or if sufficiently windfirm to provide a reliable seed source, they can be cut as a uniform shelterwood.

Uneven-aged management can be applied in Engelmann spruce and subalpine fir stands by individual tree or group selection (Alexander 1986a). Where spruce and fir occur, they are generally climax species but may or may not be major components of seral communities (Alexander and Shepperd 1984, Alexander et al. 1984). Mature stands frequently have more than one canopy story, which can decrease the time required to achieve a balanced diameter distribution. The major difference between selection and some modifications to clearcutting and shelterwood is the way growing stock is regulated. Selection is distinguished by controlling stand structure throughout a unit on the relation of numbers of trees in successively smaller diameter classes (q), the basal area of the stand, and the maximum diameter. A q between 1.3 and 1.5 is recommended as a reasonable initial goal for regulating previously unmanaged stands (Alexander and Edminster 1977). Selection is an intensive management practice that can be difficult and expensive to apply. Alexander and Edminster (1977) have suggested marking procedures for conditions common to the region.

Normally, even-aged reproduction methods are best suited to maintain vigorous, productive lodgepole pine stands because of the intolerance of the species and the prevalence of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) in mature stands (Alexander 1986c). However, it is possible to apply selection reproduction methods in mature old-growth pure or mixed lodgepole pine stands where management goals require minimal disturbance to the forest.

Clearcutting is the most common reproduction method applied in lodgepole pine stands because of the advanced age of many stands in the region and their susceptibility to insects, disease and windthrow. Where natural regeneration is dependent on a nonserotinous seed source, size of cutting units, logging plans, slash disposal and seedbed preparation should be designed to provide for seed dispersal, promote seedling establishment and create conditions favorable for growth. Effective wind dispersal of lodgepole seed limits clearcut size to a diameter of 300 to 400 feet, or about 5 to 6 times tree height on favorable sites (Lotan and Perry 1977). A bare mineral soil seedbed is the most favorable for regeneration, and can be created by broadcast burning or mechanical treatment in conjunction with logging or slash disposal, since seed is not contained in cone bearing slash.

Clearcut unit size is not limited by seed dispersal where cones are serotinous, but there is only one opportunity to

achieve successful natural regeneration. However, Alexander (1986c) sees no advantage to openings larger than 30 to 40 acres, even for dwarf mistletoe control, and smaller openings may be more consistent with non-timber resource objectives. Slash treatment alternatives are limited since the cone bearing slash must be preserved and distributed throughout the cutting unit (Tackle 1964, Alexander 1966). Slash treatment can be achieved by lopping and scattering or rolling and chopping. Bare mineral soil should be present on at least 40% of the area for suitable regeneration.

Partial cutting to regenerate an even-aged stand can be accomplished with uniform or group shelterwood where shade is required because of harsh site conditions or where management goals dictate extension of the time a mature canopy is present on the site. In group shelterwood small openings are created and regenerated in a sequence so that the regeneration in the entire stand can be treated as an even-aged management unit. Recommendations for uniform and group shelterwood are based on stand structure, windthrow risk, and insect and disease problems (Alexander 1986c). Repeated entries are recommended at five to ten year intervals or when current openings are adequately stocked. In uniform, single-storied, low windfall risk situations, a stand can be completely regenerated in 2 cutting cycles with uniform shelterwood and 3 to 4 cycles with group shelterwood. As windfall risk increases, the basal area or unit area cut in one entry decreases, and the number of cutting cycles required to completely regenerate a stand increases.

Thinning

Thinning represents the most powerful silvicultural tool available to shape the structure of naturally regenerated stands of lodgepole pine, or Engelmann spruce and subalpine fir. Precommercial thinning can be used to shorten rotations, to create economically viable management regimes, to improve stand composition, and to improve stand vigor and value, and resistance to insect attack (Long et al. 1986). Recent evidence suggests that susceptibility to mountain pine beetle attack (Berryman 1982) and defoliators such as the spruce budworm (Cates et al. 1983) is related to reduced stand vigor. Precommercial and commercial thinning can maintain high individual growth rates to maintain high stand vigor. Thinning to reduce canopy leaf area and transpiration may be effective in increasing water yield from subalpine forests (Knight et al. 1985, Troendle 1987). Habitat for various wildlife species may be improved by thinning (Crouch 1986). Ungulate hiding cover guidelines are most effectively met by sapling stands precommercially thinned to forestall the age of self-pruning of tree crowns (Smith and Long 1987).

Quantitative models are available to test the results of thinning regimes for volume production and stand structural development. Growth and yield simulation models include RMYLD, a whole stand model for even-aged and two-storied stands (Edminster 1978), and PROGNOSIS, an individual tree model, for even and uneven-aged stands (Stage 1973). Treatment effects on stand volume, tree size, and disease or insect infestations can be simulated with these models. Density management diagrams (McCarter and Long 1986) and stocking charts are useful tools for devising sound density management prescriptions to achieve specific resource goals. Increasingly, growth projection systems are being linked with production models for non timber resources. For example, stand structures meeting ungulate thermal and hiding cover guidelines are displayed on density management diagrams (Smith and Long 1987) and a hiding cover simulator is directly linked to PROGNOSIS.

Conclusions

Silviculturists have the knowledge base to prescribe stand level treatments to meet management goals specific to regional conditions as the result of the accumulated research on the Fraser Experimental Forest and throughout the region. Classification systems provide the means to characterize site specific problems and opportunities for production of various resources. Relations describing seed production and dissemination, and seedling survival with respect to microsite and topographic conditions have been generally described for natural regeneration. Guidelines are available to prescribe reproduction methods for old-growth stands of lodgepole pine, and Engelmann spruce and subalpine fir in relation to stand structure, windthrow risk and management goals. An array of quantitative tools, including simulation models and applied density management guides, are available for use in evaluating stand specific density management alternatives.

Further research in the central Rockies should proceed in two directions--developing cost effective, site-specific techniques for devising stand level prescriptions, and developing stand and landscape scale relations between stand structures and nontimber resources. More precise techniques to characterize site environmental variation are needed. Incorporation of topographic and soil influences on site may improve the resolution of classification systems (e.g. Peet 1981). Clarification of site-specific relations for seedling establishment will allow silviculturists to more closely tailor regeneration prescriptions to stand conditions. Development of techniques for less intensive applications of selection would allow more uneven-aged management practices in the region. Quantification of early growth rates and stocking relations of managed stands will lead to clearer choices for early density control to achieve desired stand structures.

Design of prescriptions to meet multiple use objectives will become increasingly important in the central Rocky Mountains. Ways to integrate individual stand prescriptions to produce desired conditions on a variety of landscape scales are needed. This will include of better understanding of the relation between specific stand structures and other compo-

nents of subalpine forests such as wildlife habitat requirements, water yield, sediment production, scenic values and recreational use.

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Practicality of Applying Silvicultural Research on Subalpine Conifer Forest

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Abstract--Silvicultural research has provided the tools that are routinely used by the practicing forester. There are many outside factors such as social, economic, political, and agency policy that affect the application of "state of the art" silvicultural practices.

Forest Types

The forest types that make up the subalpine conifer forests are lodgepole pine, (SAF forest cover type 218) and Engelmann spruce-subalpine fir (SAF forest cover type 206).

Lodgepole pine occupies 13 million acres in the Rocky Mountain and Pacific Coast areas. It is one of the most wide spread species in the western United States. In the Rocky Mountain area it grows at elevations of 6,000 to 11,500 feet where snow ranges from 120-250 inches per year (Alexander et. al. 1983).

Engelmann spruce-subalpine fir occupies 10 million acres in the western United States. In the Rocky Mountain states south of Idaho and Montana it occupies sites that range in elevation from 9,500 to 12,000 feet. It is the forest type that occupies the highest, wettest, and coldest forested continental climate in the western United States. Snowfall ranges from 150-400 + inches per year with temperatures that range from -50 to above 90° F (Alexander and Engelby 1983).

What Has Research Given Us?

Research has given the practicing forester biological information about the subalpine conifer forest that is necessary to manage the forest: items such as species longevity, shade tolerance, wind firmness, seed and seeding characteristics, site indexes and associated growth rates, site requirements and range, insect and disease susceptibility, as well as relationships with other plants and animals.

Even-aged and uneven-aged silvicultural systems have been examined and the responses of the subalpine conifer species to these systems have been documented.

Computer models have been developed to help the field forester evaluate management objective benefits, and timing and intensity of various silvicultural practices during the planning process. This allows the forester to take a look in a matter of minutes at the results of a variety of prescriptions that would take decades to evaluate if applied on the ground. Models that predict water yield and wood fiber yield have been developed and improved over the years.

Through past research various tables that the field forester takes for granted were developed. There are tables on volume, growing stock levels, site indexes and more. Rating systems for insect and disease susceptibility and severity, such as the dwarf mistletoe rating system and stand susceptibility to mountain pine beetle, have been developed.

Guidelines have been published to guide the practitioner in planting, thinning, harvesting, seed bed preparation, protection, and more.

Most early silvicultural research was done with the objective of timber management in mind. As societal values started to change, research was initiated for objectives such as water, range, visual quality, wildlife, and recreation. Even today most publications that deal with non-timber values talk about the trade-off of timber values that are necessary to implement those practices.

How Do Forest Managers Use Research Information?

Ideal

The field forester examines the forest land to determine what the existing stand characteristics and conditions are. The forester then determines what the land management objectives are for the land, combines that information with "state of the art" silvicultural knowledge and tools that have been provided by the researchers, and writes the ultimate management prescription for each stand. These prescriptions are then implemented on the ground with all appropriate records kept and filed. The forester and the forest live happily ever after--at least until the next rotation of the forest, or the forester.

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Reality

Foresters are applying "state of the art" silviculture with varying degrees of success. Success depends on many things such as land ownership and associated land management objectives, resource agency policies, societal values, politics, and the value of forest products.

Land Ownership and Associated Management Objectives

Forest land ownership can be divided into federal, state and local government, and private land. Lands owned by various governments remain in continuous ownership more so than private land. The best opportunity for applying "state of the art" silviculture is on those lands that remain in continuous ownership and are not designated as "multiple-use" lands.

Forest land management objectives vary greatly, but generally include one or more of wood fiber, water, forage, or wildlife production; recreation, healthy forest, or preservation.

Private Lands

On private land, the landowner is the only public that the forester must satisfy, except in locations where state or local forest practice acts restrict or require certain activities. The landowner sets and prioritizes the objectives for forest land management. The practicing forester can take those objectives, along with the forest stand condition, and combine them with "state of the art" silviculture to make specific prescriptions. These prescriptions are then implemented according to the landowner's time schedule.

In Colorado, most private forest land owners do not manage their forest lands for wood fiber production. Rather, they are primarily interested in maintaining a "healthy forest." Wildlife, fuel reduction, improved grazing, and forest products are secondary. Private land provides an opportunity for truly multiple use of forest lands, but it is the landowner who makes the final decision on what conflicting prescriptions have priority.

The landowners are generally willing to manage their forest lands as long as it does not cost them anything or they can realize a return of a few dollars. A few landowners are interested in recovering the value of the forest products on their land.

As long as the land base remains in the same ownership the stated management objectives are valid, thus the silvicultural practices are appropriate and will be completed over time. When ownership of forest land changes, chances are that the land management objectives will also change. Thus the recommended long-term silvicultural practices may not be completed. Small private forest ownerships make some of the silvicultural practices impractical. Practices which make a significant change in the existing forest cover are not likely to be implemented on small acreages even though the long-term objectives of the landowner would be met.

State and Local Government Lands

Most state and local government lands do not change ownership and are managed for objectives on a continuing basis. Management objectives may be multiple use in nature, but usually have a primary objective that is not disputed.

For example, lands owned by the Division of Wildlife are managed primarily for wildlife habitat. Any work done will be for the enhancement of wildlife. Benefits to other resources are incidental. Land owned by the City of Colorado Springs for watershed is managed for the protection of water quality and water yield. Other benefits are recreation, wildlife habitat, and forest products as long as they do not detract from water objectives.

Silvicultural prescriptions that are made for these primary objectives stand a good chance of being implemented over the long term. There is less chance that these objectives will be disputed and changed during the rotation.

Federal Lands

Within the federal ownership there are lands that are designated as multiple-use lands such as Bureau of Land Management and the National Forest lands. Other lands such as National Parks and Wildlife Refuges are single-use lands.

Single-use lands, similar to those of State and local government, stand a good chance of seeing silvicultural prescriptions completed.

On multiple-use lands the public has a say in the land use allocation process and the prescriptions that are made. It appears to me that no special interest groups, whether they are preservation oriented groups, grazing associations, timber associations, four-wheel-drive clubs, skiing enthusiasts, fishing and hunting groups, mineral interests, water users or any of the numerous groups, are willing to settle for their "piece of the land use allocation pie." The constant jockeying for position to try to get more land for their use hinders the forester from applying any long-term silvicultural practices on the ground.

Societal Values

This great country that we live in was built on the use, and yes, abuse of our natural resources. The attitude was that the resources would never end. There was always more resource over the next hill.

A large portion of the society that built this country was agriculture based. They were used to the rotation of preparing the site, planting, cultivating, harvesting of crops, and starting over again. Harvesting of the forest was natural to this society.

As agriculture became more efficient it took less people to feed and house the people of the Nation. This started the move from the rural to the urban areas. As the generations passed, those who lived in the country and were familiar with the agricultural process of site preparation, planting, cultivating and harvesting also passed.

The urban population, along with the rural segment of society, became more affluent and started turning to the forests for recreation. These people started to question practices such as clearcutting large blocks of forest that did not regenerate. They also questioned the practices of logger's choice, diameter limit cuts, utilization and slash disposal requirements that were the standard of the day.

These practices are often referred to as "low-intensity management" but in reality it would be more appropriate to say "No Management." The bottom line was that the forest resources were being mined.

We, as foresters, and the forest industry of the time, were using the same philosophy that was used during the expansion of the country. By using "low-intensity management," we as professional foresters lost the trust of the public as competent resource managers, and the ability to apply "state of the art" silviculture.

This was the setting that started the great public debate over how the public lands designated as "multiple-use" are in fact used. The debate not only pits preservation against consumptive use, it also divides the various types of use. For example there is conflict between the motorized recreationist and the non-motorized recreationist. The non-motorized recreationists are split between the mechanical (mountain bike) and the non-mechanical user. The non-mechanical users are split between the hiker and the horse rider.

Political

The same society that started questioning practices being used to manage the forest resources are the ones that are electing the politicians who govern the states and the Nation. This urban society provides the majority of the legislators and the powerful constituency behind them.

Legislators pass statutes to provide for input by their publics into the land management process, and they control the purse strings that ultimately control the application, or lack of application, of silvicultural practices as well as research.

Resource Agencies Policy

The natural resource management agencies are caught in the middle. They have the charge of managing the resources they have been entrusted with in a manner that will provide a sustained yield of multiple-use outputs for the public good.

Regulations are promulgated to implement the various statutes. To provide an opportunity for the public to be involved in the land management process, we provide for public hearings, and an administrative appeal process. Plans are prepared for a 50-year period with revisions every 10 years, and the possibility of amendments at any time.

The various publics that are jockeying for a larger piece of the land allocation pie have learned to use the appeal process very well. To prevent the agencies from implementing a management program they don't agree with, they can appeal the plan, or an individual project, for the cost of a postage stamp. The appeal process is used extensively as a delaying action.

If action can be delayed long enough they will have another shot at changing the land use allocation, thus the land management objectives, in the next planning period. How can the practicing foresters realistically implement silvicultural prescriptions that may take 40 or more years to complete when the objectives may change within 10 years?

In the process of negotiating a compromise with appealing special-interest groups, changes are made to prescriptions to make them acceptable. These changes may become standard over a period of time and add cost to the project.

Since many resource management objectives are implemented via the timber sales program, these additional costs make the sales appraise out at deficit, and they will probably end up being "below-cost sales." Many of these sales will not be sold because the forest products industry can not make a profit. The opponents of timber sales, and some agency managers, say the industry does not need or want the timber so they should reduce the volume offered. A vacillating and undependable supply of raw material makes the viability of the forest products business even more questionable.

Practicing foresters need to work with the timber industry in a partnership role. We have to have industry in order to complete the majority of our work. We have to realize that industry is not in business for the fun of it, or to do what is good for the forest, but is solely profit motivated.

Resource management agencies get caught up in their own bureaucracy. We are trying to be all things to all people. We want to be sure that we are responsive to our publics, and also be sure that we do everything exactly right, (to the point that we spend most of our time playing "CYA.") Professional foresters are involved in the planning process, writing environmental impact statements, taking additional training (so that we can become certified to do our job such as write management prescriptions, cruise forest stands, and scale logs), preparing budgets etc. These are necessary tasks, but with all of this there is little time to get out in the field to DO the job!

We end up hiring seasonal workers, who may be forestry students at best, to do the "on the ground" work. The best-written silvicultural prescription, if not applied correctly on the ground, will not be acceptable to our "publics" let alone ourselves. Professional foresters should be the people on the ground applying the prescriptions.

Resource management agencies have started using specialists to do various aspects of the job. One person cruises the stand, another writes the silvicultural prescription, another lays out the prescription on the ground, another designates

access roads, another writes the contract, another administers the contract, and yet another evaluates the job. Chances are that the people who initiated the project have been transferred to another job and may never see the results of what they did. No one has ownership of the job, nor has anyone learned from his own mistakes.

Other Factors

Water Law

In Colorado the water rights are allocated by law on a seniority basis. In most cases a landowner, whether private, state, or federal, does not have the right to any additional water that results from silvicultural practices. "New" water is not available to the landowner to use as a salable or usable commodity, thus there is no incentive to implement water augmentation projects.

The senior water users will get their water regardless of flow, except in drought years when the water is not there. The junior users are the ones that would probably benefit the most by water augmentation, but are reluctant to pay for water augmentation work when there is no guarantee that they will get their full allotment of water.

Road Costs

Implementation of silvicultural prescriptions, other than do nothing, requires access to the area and the stands that will be treated. Size, dispersion, and shape of treatment units will determine the amount of road required.

Research has shown that there are optimum size units for different management objectives, and species response. For example, when patches of five to eight acres are used as opposed to blocks of 40 acres, the amount of road needed to access a 30% cut increases by 250%. If these costs are to be absorbed by the timber program it become impractical for industry to operate.

Funding Levels

There are many reasons that could be discussed as to why funding is inadequate to allow full application of silvicultural practices. At this point it is sufficient to say that appropriations are not keeping pace with the cost of management for most forest resource values.

Forest managers are trying to use the timber program to implement watershed management, wildlife habitat, insect and disease protection, range, recreation programs, etc. Small cuts, additional roads, multiple entries, extensive slash treatment, and limiting entry time all add to the cost of the job. To make these modifications of a silvicultural prescription to accommodate other values adds costs which can make a break even, or marginally profitable, project lose money.

Markets and Product Value

Although the value of forest products from the subalpine conifer forests is greater than other forest types in the immediate area, it is of less value than forest products from other regions. Due to the comparative lower value of the products, the demand for products from native lumber is lower.

Combining low-valued products with the increased cost of non-timber value requirements makes the practicality of applying "state of the art" silviculture primarily through a timber sale program questionable at best.

So Why Do Anything?

I believe the public will allow and support intensive forest management as long as it realizes the value of silvicultural practices. The public requires clean harvesting that has high utilization and slash treatment standards which meet the regeneration needs of the species on land that has been allocated for treatment. We will need to increase the productivity of available lands by ensuring rapid regeneration and controlling stand density.

Foresters and the forest products industry must work together as partners to accomplish silvicultural prescriptions that are feasible. Industry must realize the constraints that are placed on the field forester as well as the type and quality of forest products that are available. Foresters have to quit asking industry to do jobs that will not pay for themselves in product value.

Research has provided "state of the art" tools for the practicing forester to use on the ground. We must use every opportunity for the researcher and the practicing forester to exchange problems and research findings. Conferences like this are a good start; but need to be more frequent, include industry and other interest group representation. Publications need to be written for the practicing forester--not other research scientists.

Management agencies must be on constant guard against practices that limit their forester's ability to apply "state of the art" silviculture.

All of us (researchers, field foresters, and industry) must work together to explain to the public "what, why, where, when, and how" silvicultural practices are beneficial to the forests.

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Silviculture Research in Rocky Mountain Aspen

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Abstract.--Recent intensification of aspen management in the central Rocky Mountains has resulted in the establishment of a silviculture research program to meet management needs. A brief history of management and past research in western aspen precedes a discussion of the results and management implications of several current silviculture studies.

Management practices for aspen (*Populus tremuloides* Michx.) forests in the central and southern Rocky Mountains have not evolved in the same manner as those for conifer forests in this region. Historically, low demand for aspen wood products resulted in little interest in intensive management or silviculture research.

However, this situation has recently changed. Demand for aspen fiber and for other resource uses has intensified aspen management in the Rockies, and created a need for additional silviculture research.

The objectives of this paper are threefold: (1) review the sequence of events that led to the current interest in aspen management, (2) briefly review the principal contributions to the silvicultural information base for western aspen, and (3) discuss current aspen silviculture research at the Rocky Mountain Forest and Range Experiment Station and summarize what we are learning.

History of Management

Aspen management within the Rocky Mountain Region has increased dramatically within the last 10 to 15 years. Before this, aspen was managed only where local commercial markets existed for aspen products, such as match splints, excelsior, paneling, sawn shakes, mine props, pallets, fence poles, and other specialty products (Koepke 1976). In most cases, only large trees free of internal defect could be used for these products, which further limited the types of stands that could be commercially managed.

Prior to 1976, aspen accounted for only 2% of the annual timber harvest in the Rocky Mountain Region (Mathiason 1976), even though aspen occupies about one-third of the forested area in Colorado alone.

Two events in 1976 marked a turning point for aspen management in the Rockies. First, an awareness of the significance of the aspen resource in the Rocky Mountain Region was reflected by an aspen utilization symposium held in Fort Collins, Colo. (USDA Forest Service 1976). Participants emphasized the unique utilization characteristics of aspen and advocated more active management of the resource. The second event was the creation of an Aspen Task Force panel by the U.S. Forest Service to examine the aspen resource in the Rocky Mountain Region. This panel submitted a draft in-house report to the Regional Forester, which also called for more active management of the aspen resource and recommended that manageable aspen stands be moved to the Commercial Forest Component in the Forest Service bookkeeping system, giving them the same management status as conifer forests.

Concurrently, managers were concerned that many aspen forests were reaching maturity and soon would be replaced by conifers at the expense of wildlife habitat and scenic vistas. In 1978, yearly aspen harvesting targets to regenerate critical aspen wildlife habitat were established in Rocky Mountain Region forests. These targets were ambitious, considering the nearly 3 million acres of aspen that eventually would have to be regenerated. Their establishment did, however, set the gears of management in motion.

In 1983, the aspen management picture changed abruptly when Louisiana Pacific announced construction of two flakeboard mills in Colorado that would utilize aspen. This market for aspen could provide a means to effectively and economically manage a much greater portion of the aspen resource.

However, managers were not fully prepared for such a sudden turn of events. The flakeboard mills had not begun operation before a controversy arose over the planning process and management guidelines used by the Forest Service to

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select aspen stands for harvest. In response to litigation brought about by the State of Colorado and a coalition of environmental groups, a panel of experts representing the principal interest groups was formed in 1984 to draft management guidelines for aspen that would be acceptable to all. The results of that effort were adopted by the Regional Forester in 1985 and are in use in the Rocky Mountain Region today (USDA Forest Service 1985).

Early Silviculture Research in Aspen

The history of aspen research in the West parallels that of aspen management. The current program at the Rocky Mountain Station is an expansion of the earlier, limited efforts throughout the West.

The most important early work in western aspen was that of Baker (1918a, 1918b, 1925). His work included descriptions of aspen growth and regeneration characteristics, development of volume tables and site index classes, and regeneration observations. Baker's studies generated much of the information available until the mid-1970s, and many of his observations and conclusions are being upheld by the more quantitative work being done today.

Arthur Sampson (1919) described aspen root suckering that occurred after complete clearfelling. He observed variable regeneration success, and noted browsing and disease problems in his Utah study areas. We are quantifying some of these same regeneration problems in our research today.

More recently, aspen research was conducted by the U.S. Forest Service at both the Rocky Mountain and Intermountain Forest and Range Experiment Stations. Two people were responsible for much of the early work in aspen at the Rocky Mountain Station.

Tom Hinds produced much of the available literature on aspen canker diseases in the West (Hinds 1964, Hinds and Krebill 1975) and their impact on aspen fiber resources (Hinds and Wengert 1977). Although retired, he remains an active cooperator on current silviculture studies.

John Jones initiated silviculture research in aspen at the Rocky Mountain Station in the mid-1960s when he published site index curves for aspen and a series of ecological and regeneration studies (Jones 1966, 1971, 1974, 1976; Jones and Trujillo 1975a, 1975b). This material served as the basis for the first draft of a book later revised and published as General Technical Report RM-119, "**Aspen: Ecology and Management in the western United States**" (DeByle and Winokur 1985).

Aspen research at the Intermountain Station was more involved. A research work unit entirely devoted to aspen was maintained by the Intermountain Station from the early 1970s until 1985. Research by Walt Mueggler, Norbert Debyle, George Schier, Dale Bartos, Bob Campbell and others greatly expanded our knowledge of the physiology, regeneration, ecology, and wildlife habitat relationships of western aspen. The numerous contributions of these researchers are summarized in Debyle and Winokur (1985).

Current Silviculture Research at the Rocky Mountain Station

Current aspen silviculture research at the Rocky Mountain Station emphasizes aspen stands that have the potential for commercial management. This research developed in response to the need for more information about how the large aspen resource in the Rockies should be managed.

Our aspen growth and yield research has included the development of volume tables (Edminster et. al. 1981, Shepperd and Mowrer 1984), site index curves (Edminster et. al. 1985), an aspen module for the RMYLD stand growth model (Edminster and Mowrer 1985), and a normal diameter distribution growth and yield model (Mowrer 1986). We also have produced equations for estimating bark thickness and past diameters (Mowrer and Edminster 1985), mean annual volume productivity (Mowrer 1986), and leaf areas (Kaufmann et. al. 1982).

We currently have several studies of growth, regeneration, and cultural activities underway in aspen. I would like to briefly share some preliminary results and observations from these studies.

The Aspen Stand Classification Study (Shepperd 1981) has been underway since 1979. This study was undertaken to meet two objectives: (1) describe the range of stand and growth conditions occurring in aspen in the central and southern Rockies, and (2) develop a classification system based on information available from Stage II inventory that would be helpful in making management decisions in existing stands.

Growth, site, and clonal characteristics from 140 aspen stands throughout Colorado and southern Wyoming were compared. A number of trends were noted (Shepperd 1981).

1. Most aspen in the Rockies is mature, from 60 to 120 years old. Younger stands are rare, but occasional old-growth (120-180 years) stands can be found.
2. Not all aspen is even-aged. About 20% of the stands encountered were two- or multi-aged.
3. Aspen grows on a variety of sites in association with both montane and subalpine vegetation.
4. Growth characteristics expressed on a clonal basis can be useful in identifying stand condition. For instance, height of live branches can be used to identify the relative age of a stand, and yellowish bark color may be indicative of stress.

A cluster analysis is being used to incorporate these and other relationships into a classification scheme based on stems per acre, average stand age, average stand height, and site index. These characteristics have been used to assign stands into one of seven preliminary classes that require different silvicultural or management considerations. Briefly, these classes are:

1. Mature, average stocking and productivity. Capable of commercial management.

2. Middle-aged, poorly stocked, low productivity. Commonly occur on dry sites. May be hard to regenerate.

3. Young, dense, fast growing sapling stands without measurable commercial volumes.

4. Young, moderately stocked, sapling stands with measurable commercial volume.

5. Mature, heavily stocked, highly productive stands. Highly suited for sustained fiber production.

6. Middle-aged, healthy, well-stocked stands with high production. Management can be deferred in these stands.

7. Very old, well-stocked stands that provide valuable wildlife habitat and aesthetic appeal.

An interactive computer program also is being developed that will be able to assign any inventoried aspen stand to one of these classes and provide a narrative of suggested management alternatives. The program will enable local managers to quickly gain an understanding of how aspen stands in a local area compare to those elsewhere in the Rockies, and to identify stands requiring special silvicultural consideration.

Another of our studies that has been underway for the past 5 years is a comparison of bulldozer pushing and chainsaw felling regeneration methods in aspen. This study was undertaken on the Yampa District of the Routt National Forest to investigate more cost-effective methods of regenerating noncommercial aspen stands. The effects of fencing to exclude domestic livestock and leaving slash on site also were investigated in this replicated split-block study.

Although sucker regeneration was quite variable, several trends were apparent. After five growing seasons, dozer-pushed areas contained more suckers than those cleared by chainsaw felling. Removing the stumps apparently stimulated the remaining lateral roots to sucker more vigorously. Fenced areas appeared to contain more suckers than unfenced areas, regardless of the regeneration technique used. Leaving slash in place may have offered some protection from animals, but did not allow as many suckers to become established and, therefore, may have been detrimental.

Bulldozer pushing, if properly applied, may be a successful regeneration technique in Rocky Mountain aspen. However, the large variation in sucker counts between replications in this study indicates that site and clonal differences also might affect aspen regeneration success, regardless of the technique used.

No silviculture research program would be complete without a thinning study. We have two underway in aspen. The first is on the Fraser Experimental Forest and is investigating the effect of a simulated commercial thinning in pole-sized, mid-aged aspen. A 1981 thinning removed 0%, 25%, 50%, and 100% of the original basal area from study areas in this stand. One posttreatment overstory growth measurement has been made, and a series of stem condition inventories have documented damage and disease progression in order to assess the effect of thinning on both growth and stand vigor. Some growth increases due to thinning may have occurred; however, mortality caused directly or indirectly by the thinning activity appears to have offset much of this growth.

Suckering response following thinning also is being monitored on permanent regeneration plots. To determine any effect of large ungulates, one-half of each thinning treatment has been fenced to exclude such animals. To date, suckering has been poor, even in the clearcut-fenced area.

The second thinning study has been installed in young aspen stands on the Routt, Gunnison, and Uncompahgre National Forests to investigate the long-term effects of early precommercial thinning. This study also will provide growth information for yield model updates. No posttreatment data have been collected, but growth increases and new suckering are both evident in some areas. Heavy snow has damaged the thinned treatments at one study site, and is another factor that should be considered before thinning young aspen in the Rockies.

Experience with these studies and data from the Routt and San Juan National Forests published by Crouch (1981, 1983, 1986) indicate that not all aspen stands regenerate well following clearcutting. This prompted us to complete a Region-wide survey of regenerated aspen stands in 1985. This survey sampled 32 areas that had been clearcut at least 5 years previously. Stocking, internal and external damage, and disease were all assessed.

Most aspen suckers were found to have some type of damage or defect. The effects of damage on sucker vigor appear to be additive. With the exception of disease outbreaks, stands appear to successfully regenerate where initial suckering is prolific and suckers are not damaged repeatedly or by multiple agents. Relationships between sucker establishment, site conditions, and preexisting stand characteristics will be investigated in future research.

The Rocky Mountain Station recently sponsored a cooperative study with Colorado State University on the persistence of isolated aspen clones. Several size and age classes were found in each of the isolated clones that were examined, but age classes were not evenly distributed throughout the clones. The investigators proposed that nonforest areas surrounding isolated clones may be colonized when a group of young suckers persists on the periphery of the clone.[2] The rates and directions of clonal expansion observed in this study were quite variable, and may not be related to stand or physiographic characteristics.

Future Research Needs

Although we have gained a better understanding of the management of aspen in the Rocky Mountains, many unan-

[2]Smith, Frederick W. and Kirk Apt. 1987. Persistence of isolated Populus tremuloides Michx. clones in the central Rocky Mountains. Unpublished report on file, Rocky Mountain Forest and Range Experiment Station.

swered questions remain. More aspen is now being harvested annually in the Rockies than ever before. Not all of these harvested acres are regenerating well. Understanding this variation in regeneration following clearcutting is of primary importance.

More information is needed on the condition, density, and development of the lateral root systems of mature aspen stands. We need to know how lateral root systems change as new stands develop following the harvest, as well as how the harvesting practices themselves affect lateral root system development. For instance, aerial and ground reconnaissance has shown poor stocking on skid trails and landings in some areas. We need to know whether these nonstocked areas are due to soil compaction or root system disturbance, and what conditions contribute to it.

Additional silviculture research also is needed in mixed aspen-conifer stand types. These stands offer a great deal of diversity, and provide quality habitat for many wildlife species. Such stands have traditionally been considered seral to conifers; however, evidence suggests that some of these stands have existed in a mixed overstory mode for some time. Understanding the dynamics of these stands could lead to the development of cultural practices to either maintain or perhaps establish a mixed species condition. Such techniques would not only benefit wildlife, but visual, timber, and watershed resources as well.

In conclusion, although aspen has only recently joined the ranks of intensively managed species in the central and southern Rockies, current management practice has benefited from an ongoing silviculture research program. Future management of the subalpine forest ecosystem will build upon this research base to maintain and enhance our unique aspen resource.

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Case Studies in the Application of Aspen Research

Robert T. Beeson[1]

Abstract--This paper examines current conditions, issues and concerns in Rocky Mountain aspen management from the land manager's viewpoint. The application of research is identified and suggested areas for targeting new research identified. The public's concern for aspen treatment is analyzed.

There are 3.5 million acres of aspen timberland in Colorado; 850,000 of these acres are on State and private lands. Prior to installation of the two waferwood plants, the annual harvest was in the neighborhood of 45,500 tons per year. This has increased to 250,000 tons. Several issues and concerns have arisen during the past few years as a result of this increase which will be discussed in this paper. Current application of research and silvicultural conflicts also will be identified.

Historical Perspective

The visual values of aspen have long been recognized as contributing significantly to the State's and Region's economy. The tree is more well known than blue spruce, Colorado's State tree or any other species. A major ski area is named after the tree. It is known by several names. To most ranchers it is a quakie. To people from Minnesota it may be popple. To several species of wildlife it is known as food or shelter. To foresters it used to be known as a weed and now is considered a fast growing public relations problem. The primary silvicultural problem is regeneration--too much of it and in a few cases not enough. Regulation of quantity and quality of these stems is of primary concern to ranchers as well.

Significant effort has been made to involve the public in planning for management of aspen but to date, a large percentage of the production of the two waferwood plants has been harvested from private and State lands because of continuing public concern and appeals of timber sales and forest plans. The management implications of this level of harvest from relatively small ownerships is a concern both to industry and service foresters.

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Current Issues

The foresters' concerns are the advanced age of the majority of this unregulated acreage and the possible succession to coniferous species. Given the current market, foresters have responded to these concerns by attempting to develop timber sales programs that greatly expand aspen regeneration programs.

Because of public concern, management programs on public lands have not proceeded to implementation. It is estimated that eight to ten thousand acres of predominantly private lands are being annually harvested which represents one percent of the total ownership.

Sampson (1919) identified the need to protect young stands from overgrazing. He recommends moderate grazing by cattle as a means to maintain land productivity from both range and timber standpoints. From experience in stands regenerated in 1984, significant variation occurs between cutting units in the amount of damage done to sprouts. Generally at least 3,000 sprouts per acre have reached four feet heights undamaged.

From the stockman's standpoint, two concerns seem to prevail. Excessive regeneration is seen to be an impediment to access. One of the suggested ways to limit regeneration is to leave a moderate amount of slash on the ground. This practice limits access according to many ranchers. They would prefer no slash at all. The current practice of mechanical harvesting, whole tree skidding with tops piled at landings seems to be a reasonable compromise to leave enough slash to slightly limit grazing thereby allowing adequate undamaged sprouts to overtop livestock.

Then what do we do with the slash piles? These are large and more often than not, not very flammable. Attempts were made two years in a row to burn piles at Carter Mountain after adequate snowfall. The piles are still there but another attempt

will be made this year prior to snowfall. The expense of slash disposal could exceed the revenue from the sale if this next attempt is not successful. Research needs here are to identify the best method of economical slash treatment from a multiple use standpoint. This treatment should leave enough on the site to impair some grazing but still be acceptable to the stockman who must herd and gather the cattle. The method should also leave the harvest "looking good" to the public and be cost effective (not more than $20 per acre total cost).

On moist sites, there is a concern that regeneration will not occur due to the rise in the water table that occurs due to removal of aspen which is a significant water user. On fuller saturation in the spring, this could also lead to land stability problems. We have not experienced this to date, because we have not harvested on excessively wet sites, but it is very evident in some unharvested sites.

Significant acreage of mixed aspen conifer stands exist. The predominant conifer is subalpine fir, which currently has limited value as timber. In general, prescriptions call for its removal during aspen regeneration. This is usually possible if the volume is not excessive. One advantage to having conifers included in the sale is that slash piles that are mixed are more flammable. In several cutting units installed to date, conifers which were considered wind firm were left standing. This practice has produced less visual impact while allowing regeneration of more than 20,000 sprouts per acre.

No real effort has been made to relate densities of sprouts surviving grazing to this size of cutting units. Wayne Shepperd, working closely with field foresters, feels there is a size of cutting unit that is too small. The results, if very small units are installed in areas grazed by livestock or wildlife, could be destruction of regeneration. Current practice usually is to design sales with ten acre and greater cutting units. Some unregulated private land sales have very large cutting units depending on the landowners objective. I feel we should pay close attention to cutting unit size in sale design and direct research towards identifying the lower unit size threshold where regeneration becomes uncertain.

All of these concerns are irrelevant if we cannot satisfy the public concern and major issue. This issue is whether aspen will receive any silvicultural treatment at all. This public concern is rooted in the belief that harvest of a renewable resource best be left to natural agents.

Support is garnered for this belief from factual and emotional reasoning. Some facts cited are:

1. It costs more to harvest aspen than is returned to the treasury. This can be true when costs are driven up by over planning. The current regional average cost of timber sales is over half planning before a single piece of flagging is tied to a tree.

2. The age class structure is predominantly mature and over mature but nature will take care of itself. Aspen will not disappear and succeed to conifers if left alone. The fact that 20% of the stands in Wayne's study are two- or more storied is evidence that most aspen will regenerate without logging.

An emotional concern is that harvesting of aspen is actually killing a stand rather than regenerating a new one. This concern arises from a belief that forest conditions are more static in nature than they actually are and a basic mistrust of the knowledge of foresters in predicting future conditions.

Foresters have responded to public concerns with detailed public involvement processes that more often do not influence basic beliefs that underlie the voiced concern. Usually the great majority of the so called public could care less until they are directly influenced. Harvesting is okay until the particular stand or tree that I am interested in is affected. This public does not participate in the decision making process but responds negatively when they feel threatened. I personally have no answers to this situation but have found that one on one show me trips of both successes and failures are the most effective public involvement.

Case Histories

Carter Mountain

This 5,000-acre block of state land was inventoried in 1982. Three thousand acres are forested with aspen and aspen-fir mixtures. It is located twenty miles from Kremmling. The management plan calls for harvest of 115 acres per year. Three grazing leases exist at one A.U. per 5 acres. Four hundred acres were sold in 1983 to Louisiana Pacific. The average unit size is 42 acres with a range from 12 to 60 acres. Logging was mechanical (sheared and whole tree skidded). As of 1987, all units are stocked with a minimum of 18,000 aspen per acre. Grazing has left enough undamaged stems to fully stock the area. Continuing problems are the rancher's concern about access because of high sprout density and the difficulty of slash disposal. Also, one cutting unit has a high rate of infection with a disease that looks like Shepherd's crook.

AMAX

In 1984 and 1985, 140 acres of aspen were harvested under a management program. Unit size varies from 10 to 40 acres. The two small units are within 0.25 mile from meadow or sage; the larger units are 200 feet higher in elevation. Grazing has not been excluded. Approximately 200 yearlings use the 1,500-acre allotment from June to October. The smaller, lower units produced 8,000 or more first-year sprouts; but most were damaged or killed by grazing. The larger, higher units are successfully stocked with undamaged stems.

Summary

The forester is attempting to "speak for the trees" when he or she sees large acreages of over-mature stands and designs

a schedule for replacing these forests with younger, more diverse stands. The landowners, either private or the tax paying public, feel threatened by this planned change and questions why? If there is doubt in the forester, it may be expressed by an inadequate response, anger or an attempt to hide the work that is progressing. We must be sure as foresters, that we really operate from knowledge of the facts before we "speak for the trees." We must also realize that most people do not understand the connection between the natural resources they use abundantly, their own livelihood, and the economy of the community in which they live. The only new wealth is either grown from or mined from the ground. If we let the number of people whose livelihood is directly dependent on producing this wealth equal one, then those who indirectly benefit but whose livelihood depends on its continued production equals 10. This secondary group has 10 times the influence in decisions, but is the most difficult to communicate with. They are too busy to participate or feel higher priority needs.

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Growth and Yield of Subalpine Conifer Stands in the Central Rocky Mountains

Carleton B. Edminster[1]

Abstract--Potential production of managed, even-aged stands of Engelmann spruce-subalpine fir and lodgepole pine is estimated for combinations of stand density, site quality, and rotations using whole stand growth models. Volume production is maximized at relatively high stand densities. Average maximum density curves are developed as a reference level for stocking standards.

Subalpine forests of Engelmann spruce *(Picea engelmannii)*-subalpine fir *(Abies lasiocarpa)* and lodgepole pine *(Pinus contorta)* are the largest and most productive timber resource in the central Rocky Mountains (Choate 1963, Miller and Choate 1964). Management of these forests affects all resources and uses. If total cubic volume production is the primary objective, stand densities should be maintained at relatively high levels.

Control of stand density offers the greatest opportunity for increased sawtimber production, increased tree and stand growth, reduced mortality, and creation of stand structures to meet other resource objectives. Forage production and water yield are substantially increased only at much lower densities. Low to medium densities are generally required to improve developed recreational opportunities and enhance foreground esthetics.

This paper presents projections of stand growth and yield for Engelmann spruce-subalpine fir and lodgepole pine, and demonstrates methods to standardize stocking guidelines for control of stand density. Comparisons of managed stands are developed from whole stand growth models for managed even-aged stands in the central Rocky Mountains. Comparisons follow a format similar to that used by Alexander and Edminster (1980, 1981) for examining the effects of repeated thinnings at various intensities for a range of site qualities and rotation ages. Management regimes examined appear to be the most reasonable based on past analysis and the silvical characteristics of the species. Related to estimates of growth and yield are methods for providing a standardized concept of stocking. Recent results in developing reference stocking levels in the standard national format (Ernst and Knapp 1985) for major subalpine forest types are also presented.

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Development of Models

The original models for computing variable density yield tables for managed even-aged stands of spruce-fir, SPRYLD (Alexander et al. 1975), and lodgepole pine, LPMIST (Myers et al. 1971), provide the basic stand growth and yield relationships incorporated into the whole stand model, RMYLD (Edminster 1978). The whole stand, characterized by average values, is the primary model unit. RMYLD projects stand development by consecutive 10-year periods, and includes relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre.

For both forest types, the relationship to estimate periodic mortality for a specific set of stand conditions is relatively weak. Separate relationships express the effects of and changes in the intensity of infestation of dwarf mistletoe *(Arceuthobium americanum* Nutt. ex Engel.) in lodgepole pine stands. Total cubic-foot and merchantable volumes per unit area are calculated with stand volume equations. Relationships to estimate changes in average stand diameter and dominant and codominant height and number of trees resulting from intermediate cuttings are developed from results of simulated thinnings and trial marking in growth prediction plots.

When the original models were developed, thinned stands were available only in lodgepole pine, and those did not adequately represent the range of stand conditions necessary to develop growth and yield relationships. Many of the temporary growth plots used for the lodgepole pine model and all of the plots used for the spruce-fir model were established in undisturbed even-aged stands chosen to approximate managed stand conditions. The plots conformed to usual requirements for uniformity of site quality, range in tree sizes, and stand density across the plot. Plots were placed in areas

without catastrophic mortality, and the models are not capable of simulating such effects. A single set of growth and mortality relationships is used in the spruce-fir model for both Engelmann spruce and subalpine fir. Data analysis verified that spruce and fir growth were similar for at least 90 to 100 years. Periodic thinnings are assumed to remove most of the fir component before stand age 90, resulting in a nearly pure spruce stand.

Stand Conditions Simulated

Yields were simulated for the following range of initial stand conditions and management controls for spruce-fir stands:

1. Average age at the initial entry is 30 years. Note that the age in the yield table is measured at breast height (b.h., 4.5 feet). A minimum of 20 years is allowed for spruce and fir trees to regenerate and grow to 4.5 feet in height. Therefore, total stand age is at least 20 years older than the age measured at b.h.
2. Diameter of the tree of average basal area is 4.5 inches at b.h.
3. Stand density is 800 trees per acre.
4. Site indexes at b.h. age 100 years are 50, 70, and 90 feet (Alexander 1967).
5. Rotation lengths are 120, 140, and 160 years, with a two-cut shelterwood regeneration cutting method.
6. Periodic thinnings from below begin at age 30 years and are repeated every 30 years. Thinnings are made to growing stock levels 40, 60, 80, 100, 120, 140, 160, and 180. Growing stock level (GSL) is defined as the residual basal area per acre when average stand diameter is 10 inches or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1967). Initial and subsequent thinnings are made to the same GSL.
7. Minimum size for inclusion in board-foot volume determination is 8 inches d.b.h. to a 6-inch top. Volumes are determined from tables prepared by Myers and Edminster (1972). Sawtimber volume is calculated for stands with average stand d.b.h. 8 inches and larger.

Yields were simulated for the following range of initial stand conditions and management controls for lodgepole pine stands.

1. Average total age at the initial entry is 30 years.
2. Average stand diameter is 4.5 inches at b.h.
3. Stand density is 1,000 trees per acre.
4. Site indexes at age 100 years are 50, 60, 70, and 80 feet (Alexander 1966).
5. Rotation lengths are 80 and 120 years, with a clearcut regeneration cutting method.
6. Periodic thinnings from below begin at age 30 years and are repeated every 30 years. Thinnings are made to GSLs 40, 60, 80, 100, 120, 140, and 160. Initial and subsequent thinnings are made to the same GSL.
7. Minimum size for inclusion in board-foot volume determination is 6.5 inches d.b.h. to a 6-inch top. Volumes are determined from tables prepared by Myers (1964, 1969). Sawtimber volume is calculated for stands with average stand d.b.h. 7 inches and larger.
8. Stands are not infested by dwarf mistletoe.

A 30-year cutting cycle was chosen because of low stumpage values and the need for cultural operations to produce commercial volumes. Length of thinning cycles has been demonstrated to have little effect on total yields (Alexander and Edminster 1980, 1981). All volume computations are based on gross volume equations with no reduction for defect. Also, stands were assumed to be fully stockable.

Growth and Yield Results

Diameter Growth

Periodic diameter growth of spruce-fir and lodgepole pine stands is negatively correlated with stand density (as represented by stand basal area), but positively correlated with site index. On an average site (index 70) for spruce, average diameters at rotation for spruce-fir stands are 25.5 to 39.5 inches at GSL 40 for rotations of 120 to 160 years. At very high stand density (GSL 180) average diameters range from 13.5 to 22.1 inches, depending on rotation age. On an average site (index 60) for lodgepole pine, average diameters at rotation ranged from 12.7 to 18.9 inches at GSL 40 for rotations of 80 and 120, respectively. At high density (GSL 160), average diameters range from 8.2 to 10.6 inches. Diameter growth at low stand densities may be underestimated because most data used in model development came from natural stands.

The number of precommercial thinnings required is directly related to the size of trees cut at each thinning. GSL and site quality influence the number of precommercial thinnings required if periodic thinnings are made to a constant GSL. For spruce-fir on site index 50 land, a GSL of 60 or above requires more than one precommercial thinning. At site index 70, the GSL may be increased to 100, and at site index 90, the GSL may be increased to 140, with only one precommercial thinning

required. For lodgepole pine, at site indexes 50 and 60, thinnings to GSLs above 60 require more than one precommercial thinning. For site index 70, GSLs of 80 and below result in only one precommercial thinning. The manager does have some flexibility by increasing GSLs with successive thinnings to overcome limitations on a number of precommercial thinnings with higher initial GSLs.

Height Growth

Periodic dominant and codominant height growth of both spruce-fir and lodgepole pine increases with site index and decreases with age, but is influenced little by GSLs in the range examined. However, since fewer and, therefore, taller trees remain after each thinning from below, the mean height of residual trees is negatively correlated with GSL.

Basal Area Increment

Periodic basal area increment is positively correlated with stand density and site quality. Since residual basal area increases in a stand until average diameter reaches 10 inches, at which point thinning reduces basal area to a fixed GSL amount, the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment is greater at higher GSLs, but the rate of increase declines at higher densities. Basal area increment is also greater at higher site indexes, and differences between site classes become greater with higher GSLs.

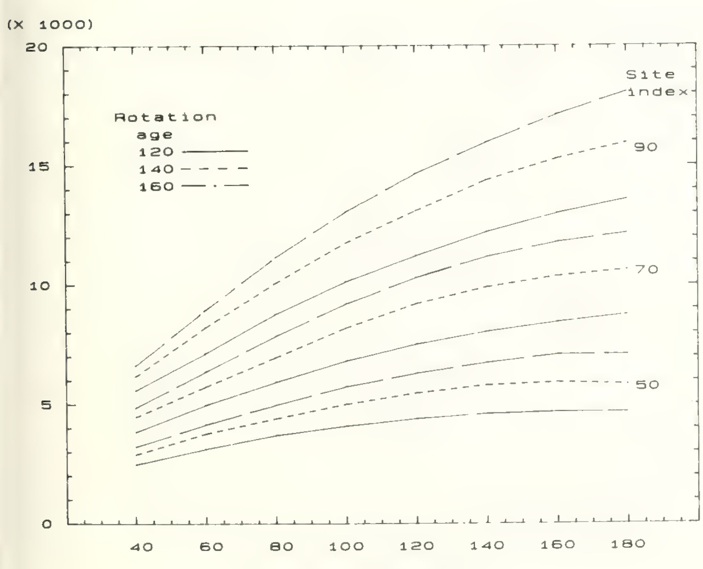

Figure 1.--Estimated total cubic-foot volume production per acre in spruce-fir stands in relation to growing stock level, site index, and rotation age.

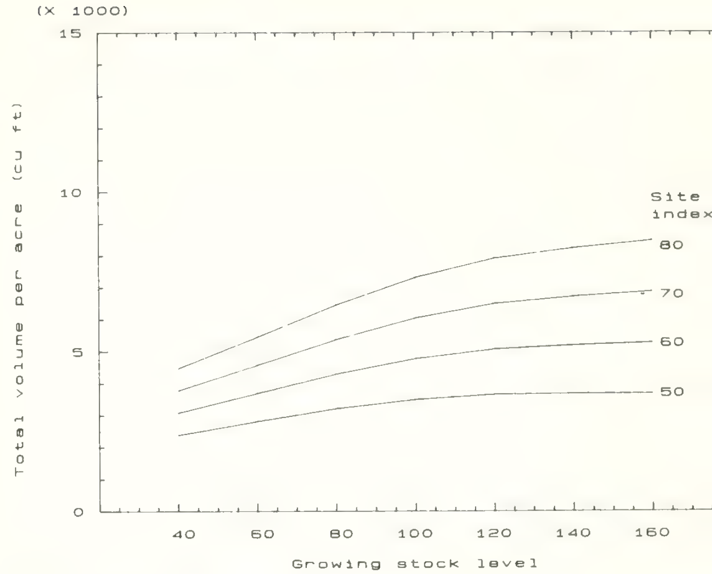

Figure 2.--Estimated total cubic-foot volume production per acre in lodgepole pine stands in relation to growing stock level and site index for an 80-year rotation age.

Total Cubic-Foot Volume Production and Increment

Cubic-foot volume production is related to stand density, site quality, and rotation age for both spruce-fir and lodgepole pine (figs. 1, 2, 3). Volume production includes periodic removals and final harvest. Although cubic volume production increases with increasing GSL and site index, the rate of increase decreases as GSL increases. Cubic volume production increases modestly at GSLs above 180 for spruce-fir and

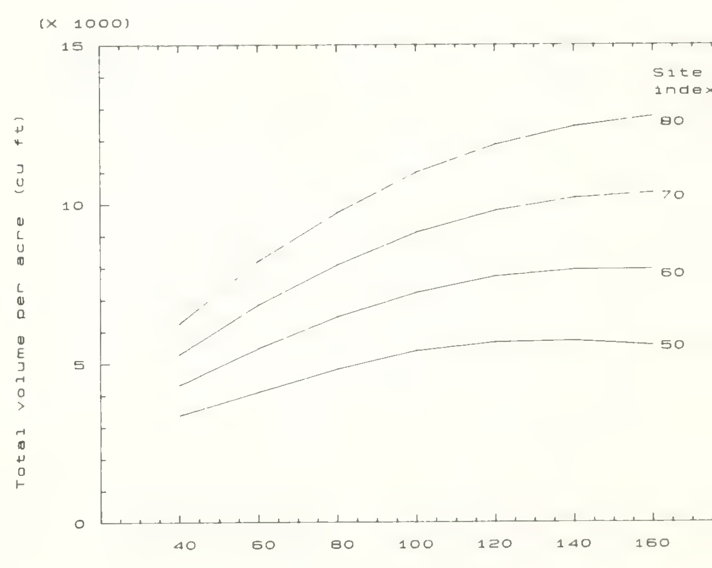

Figure 3.--Estimated total cubic-foot volume production per acre in lodgepole pine stands in relation to growing stock level and site index for a 120-year rotation age.

above 160 for lodgepole pine on all but site index 50 lands. Volume production for spruce-fir is progressively greater at increased site index. For lodgepole pine, however, the increase in production is relatively constant with increasing site index. While direct comparison of lands with equal site index is not possible for the two forest types, productivity of site index 50 and 70 lodgepole pine stands with a 120-year rotation is greater than site index 50 and 70 spruce-fir stands. At higher site indexes, spruce-fir is more productive than lodgepole pine.

Mean annual total cubic volume increment at rotation age is also related to stand density and site quality, but rotation age has little influence on mean annual increment (figs. 4, 5). The relative lack of effect of rotation age is not surprising, because repeated thinnings extend the point of culmination of mean annual increment to a plateau often extending over a wide range of stand ages. Mean annual increment is again progressively greater with increasing site index for spruce-fir, but for lodgepole pine the site index effect remains relatively constant.

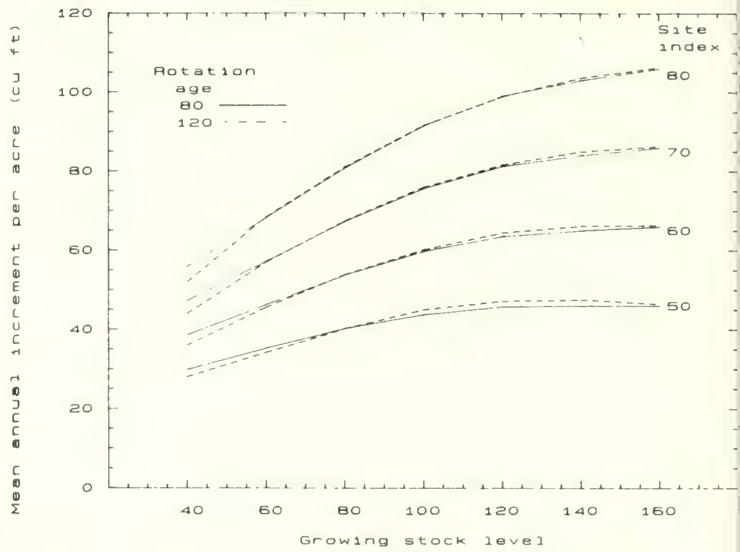

Figure 5.--Estimated mean annual total cubic-foot volume increment at rotation in lodgepole pine stands in relation to growing stock level, site index, and rotation age.

Board-Foot Volume Production and Increment

Board-foot volume production is related to stand density, site quality, and rotation age for spruce-fir (fig. 6) and lodgepole pine. Although board-foot volume production increases with increasing GSL and site index, the rate of increase diminishes with greater GSLs. Timber production increases only slightly at GSLs above 180 for spruce-fir and above 160 for lodgepole pine on all but site index 50 lands. Spruce-fir sawtimber production is again progressively greater at increased site index. However, lodgepole pine production is directly correlated with increasing site index.

Mean annual board-foot volume increment at rotation age is also related to stand density and site quality, and rotation age has a greater influence on board foot than on total cubic mean annual increment (figs. 7, 8). Average tree size increases with longer rotations, and tree size has a pronounced effect on merchantable volume calculations. Mean annual increment is again progressively greater with increasing site index for spruce-fir, but for lodgepole pine the site index effect remains relatively constant.

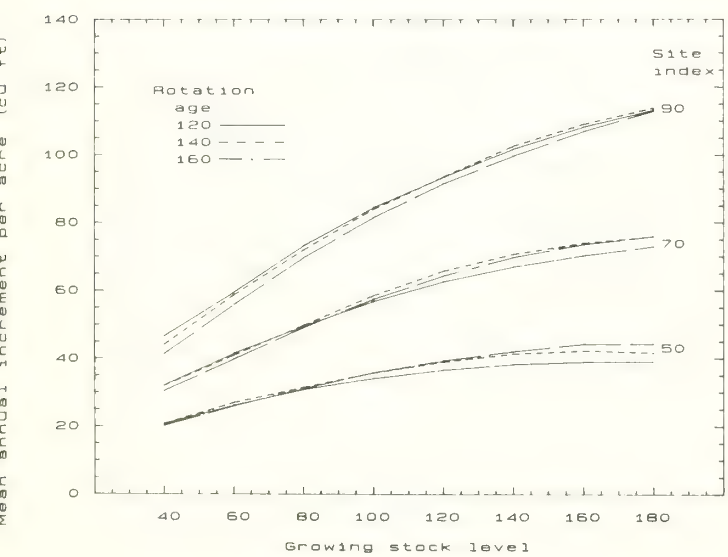

Figure 4.--Estimated mean annual total cubic-foot volume increment at rotation in spruce-fir stands in relation to growing stock level, site index, and rotation age.

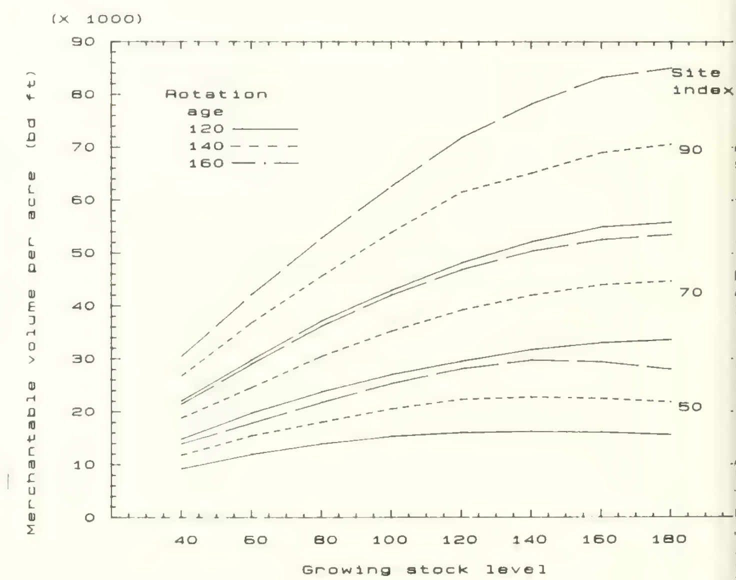

Figure 6.--Estimated board-foot volume production per acre in spruce-fir stands in relation to growing stock level, site index, and rotation age.

Management Caution

Growth responses and productivity estimates presented appear reasonable within the limits of current knowledge. However, no spruce-fir or lodgepole pine stand has been under management for the better portion of a rotation, and in some situations, the simulations extend beyond the limits of the available data base. Comparisons of estimated values with actual values from permanent plots are needed to verify the growth and yield projections. An example of such a comparison is the levels-of-growing-stock study in lodgepole pine that will be visited on the field trip.

Reference Curves for Stocking Charts

A major provision of the National Forest Management Act of 1976 is that forest lands in the National Forest System be maintained at appropriate stocking to secure maximum benefits of multiple-use, sustained yield management. Several formats are available for stocking guides for the major forest types. An example is the growing stock levels developed by Myers (1967) for ponderosa pine and used in the above yield projections to index stand density after partial cutting.

The Forest Service selected the Gingrich (1967) stocking guide format as a standard to assist with the consistent application of stocking guidelines (Ernst and Knapp 1985). The relative simplicity of the Gingrich stocking guide makes it especially attractive as a communication tool when land managers must consider multiresource management. In addition, Curtis (1970) demonstrated the ease of converting from many other frequently used stand density measures. However, stocking charts apply only to a specific forest type, often a single species, and simple stand structures with unimodal

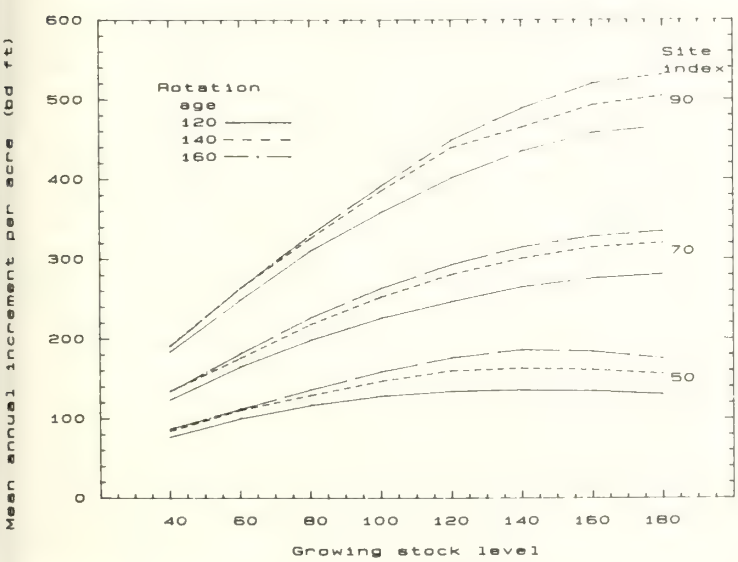

Figure 7.--Estimated mean annual board-foot volume increment at rotation in spruce-fir stands in relation to growing stock level, site index, and rotation age.

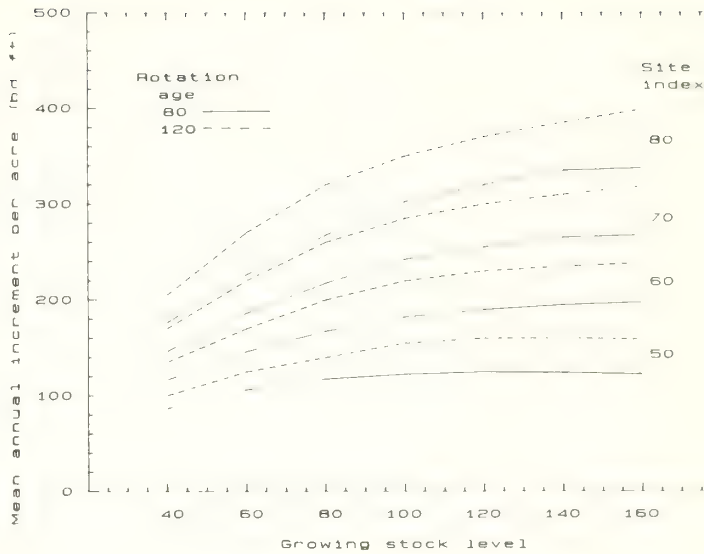

Figure 8.--Estimated mean annual board-foot volume increment at rotation in lodgepole pine stands in relation to growing stock level, site index, and rotation age.

diameter distributions. In the central Rocky Mountains, these limitations are generally not critical due to relatively simple species composition and structure in the majority of forest stands.

The Gingrich guide displays stand basal area as a function of number of trees and quadratic mean diameter (DQ). The reference level for the guide is the absolute stand density at average maximum competition. Many stocking charts have been developed from tree-area relationships, and this procedure is well documented (Chisman and Schumacher 1940, Gingrich 1967). The procedure for developing the reference level for forest types where tree-area relationships are not available has not been adequately documented.

Earlier this year, the Rocky Mountain Region provided a data set for natural stands to develop reference levels for stocking charts of the Engelmann spruce-subalpine fir, lodgepole pine, and aspen forest types. Stand selection criteria for the analysis included: (1) the tree species used for site index determination must correspond to the recorded forest type; (2) at least 80% of the species composition, in terms of basal area, must match the forest type; (3) at least 90% of the sample points in the stand must have tallied trees and the DQ must be at least 1.0 inch; and (4) stands must be relatively even-aged. It was not possible to directly screen this fourth criterion from the elements in the data base. As an alternative, a criterion of narrow diameter distribution was used, with stands having at least 80% of their basal area in diameter classes 1 to 9 inches, 5 to 16 inches, or 9 inches and larger being selected. The resulting data set contained 4,440 spruce-fir, 7,918 lodgepole pine, and 2,204 aspen stands.

The goal of the analysis was to derive the reference level known as the average maximum density (AMD) relationship--stand basal area per acre (BA) as a function of trees per acre

(TPA)--directly from the data set. The AMD curve is an average upper limit of observed BA across the range of TPA. Various selection criteria were applied to further select the average maximum BA values for each forest type, while providing an adequate representation of the range of TPA. After many trials and examination of resulting AMD curves, stands with the upper 2% of stand density index (SDI) values were selected (Reineke 1933). SDI for each stand was computed using the following equation:

$$SDI = TPA\,(DQ/10)^{1.6} \quad [1]$$

Characteristics of stands with SDI values in the upper 2% for each forest type are summarized in table 1. The analysis to develop the AMD curve for each forest type involved two major steps. First, the data points were plotted on a lnDQ versus lnTPA graph, where ln is the natural logarithm. A simple linear regression was fit to the transformed data of the form:

$$\ln DQ = b_0 + b_1 \ln TPA \quad [2]$$

The next step was to transform the estimated coefficients from the first step to a BA versus TPA scale. These transformed estimates were then used as starting values in nonlinear regression of the form:

$$BA = b_2\,TPA^{b_3} \quad [3]$$

Table 1.--Characteristics of natural stands with SDI values in the upper 2% for each forest type.

Characteristic	Mean	Min.	Max.
Spruce-fir			
Trees per acre	863	239	2,700
Basal area per acre (ft2)	323	240	425
Average diameter (inches)	8.9	4.0	17.8
SDI	626	575	757
Age	128	62	256
Site index (feet)	70	40	102
Lodgepole pine			
Trees per acre	2,185	662	6,700
Basal area per acre (ft2)	249	180	316
Average diameter (inches)	5.0	2.3	9.1
SDI	609	556	728
Age	94	40	181
Site index (feet)	52	26	81
Aspen			
Trees per acre	1,172	646	2,920
Basal area per acre (ft2)	307	264	359
Average diameter (inches)	7.2	4.1	9.9
SDI	644	592	755
Age	83	46	141
Site index (feet)	66	39	89

Table 2.--Results of fitting the curve of basal area over number of trees per acre (eq. 2) for subalpine stands representing the upper 2% SDI values.

Forest type	b_2	b_3	R^2	S_{y+x}
Engelmann spruce-subalpine fir	1287.091	-0.207	0.459	30.4
Lodgepole pine	1034.509	-0.189	0.586	18.8
Aspen	918.340	-0.156	0.275	24.1

Results of the nonlinear regression analysis are summarized in table 2. Data and resulting curves are shown in figures 9, 10, and 11 for spruce-fir, lodgepole pine, and aspen, respectively. The R^2 values in table 2 are the proportion of the corrected total sums of squares of basal area accounted for by the regression.

The AMD curves for the three forest types are shown together in figure 12. As expected, the lodgepole pine curve lies below the curve for more shade tolerant spruce and fir. The spruce-fir curve also lies above the aspen curve for stand densities less than approximately 750 trees per acre, but the aspen curve is the highest for dense stands. This may result from dense regeneration characteristics of aspen, which generates suckers from an existing mature root stock.

The next step in developing the stocking charts will be to superimpose management zones in the area below the AMD curves for each species. These management zones should be based on estimated timber production from simulations as described above. This step will be done with interaction from forest managers to ensure management goals can be met within the zone.

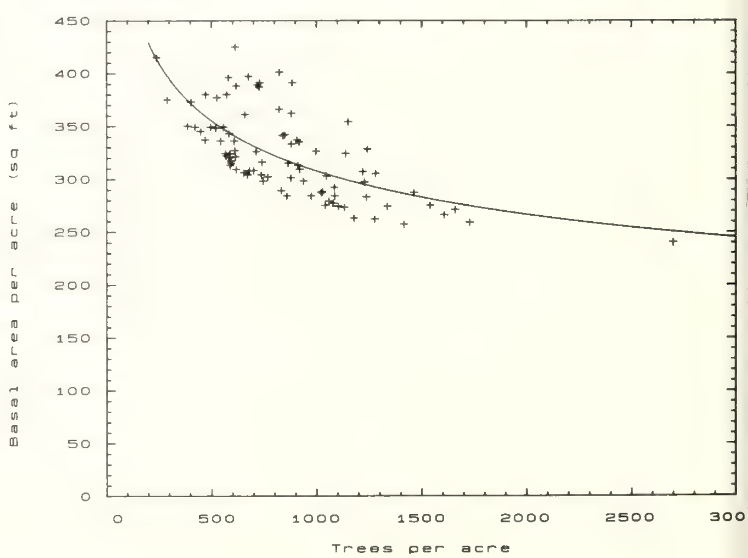

Figure 9.--Relationship of basal area to trees per acre for spruce-fir plots with upper 2% stand density index values.

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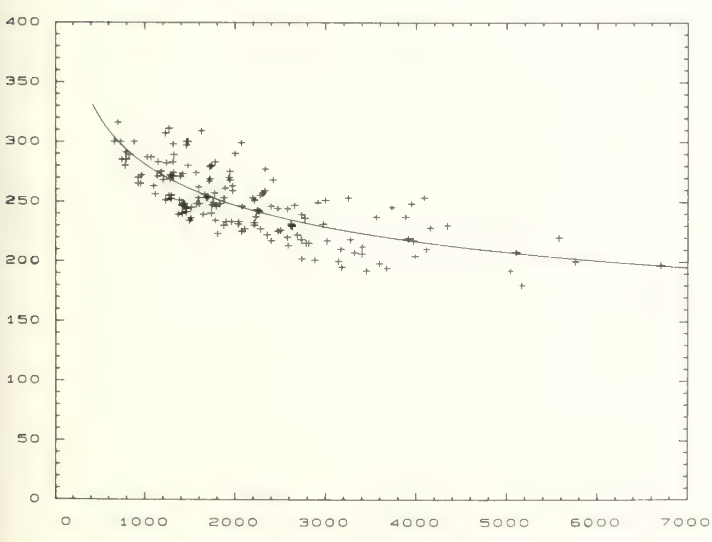

Figure 10.--Relationship of basal area to trees per acre for lodgepole pine plots with upper 2% stand density index values.

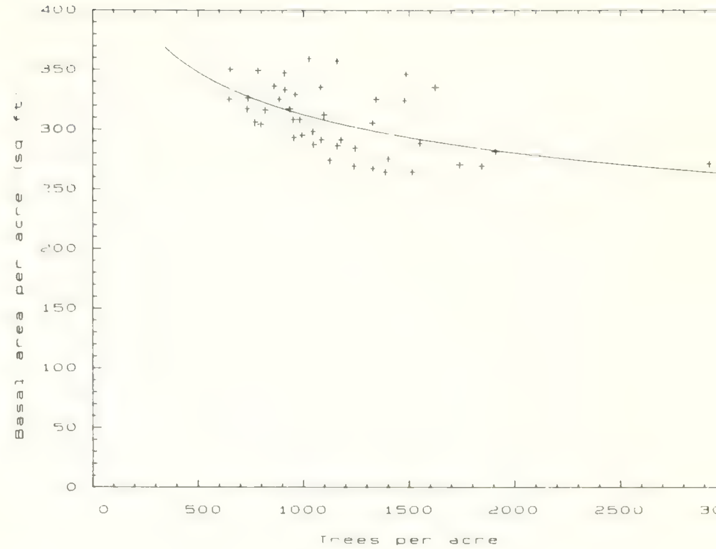

Figure 11.--Relationship of basal area to trees per acre for aspen pine plots with upper 2% stand density index values.

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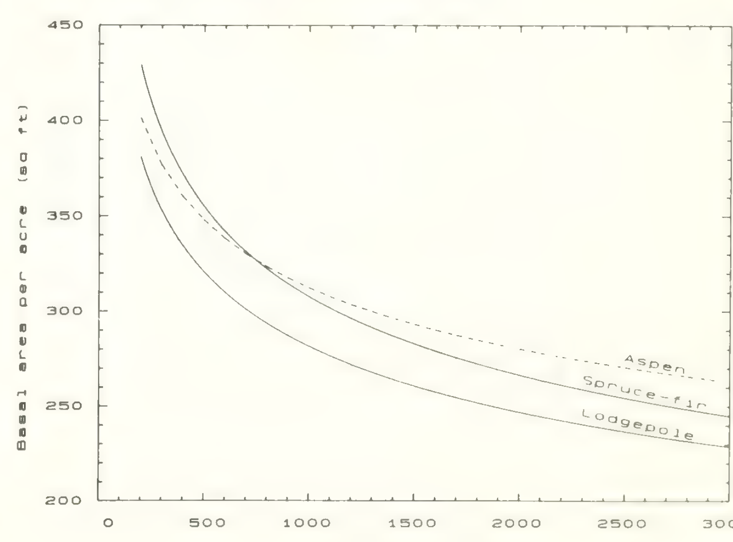

Figure 12.--Comparison of average maximum density curves for spruce-fir, lodgepole pine, and aspen stands.

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Growth and Yield of Aspen in the Central Rocky Mountains

H. Todd Mowrer[1]

Abstract--This paper provides an overview of the mensurational procedures available for aspen management in the central Rocky Mountains, and compares the relative precision of two aspen growth and yield models using a Monte Carlo technique.

An increased interest in aspen in the mid-1970s resulted in a mensurational research effort to provide improved management tools for the central Rocky Mountains. The resulting studies have improved prediction techniques for aspen growth and yield, integrated many of these techniques into two growth and yield models, and provided estimates of the reliability of the resulting projections. The variance estimation technique described here is applicable not only to growth and yield models, but to many other types and combinations of natural resource models as well.

Aspen Management Tools

Site quality indicates the interaction of genetic and environmental factors on tree growth. Site index, a commonly used indicator of site quality, expresses the relationship between tree height and age. New site index curves for aspen (Edminster et al. 1985) provide an improved basis for evaluating the productive potential of the species, particularly at earlier ages.

The culmination of volume growth, or the point of maximum mean annual growth, indicates the maximum productive potential of an aspen stand. Site index serves as a useful predictor for this maximum. With additional information on stand basal area, productivity of aspen stands at culmination of growth may be estimated by a recently published set of equations predicting mean annual increment at volume culmination (Mowrer 1986a).

Periodic tree growth may be calculated from temporary plot measurements in aspen using radial growth increment and bark thickness relationships (Mowrer and Edminster 1985). This radial increment, as well as tree age, may be efficiently measured in the field using recently published measurement techniques for aspen (Mowrer and Shepperd 1987).

[1]Research Forester, Rocky Mountain Forest and Range Experiment Station. Station headquarters is in Fort Collins, in cooperation with Colorado State University.

Volume yield for individual trees may be estimated using tables, equations, and point sampling factors developed by Edminster et al. (1982). When point samples are measured within an even-aged clone of aspen, average stand volume may be estimated directly from basal area and average height (Shepperd and Mowrer 1984).

These tools help in evaluating the productive potential of an aspen stand and in measuring the current level of stand performance. Estimates of future stand development can be obtained from two growth and yield models for pure, even-aged stands of aspen in the central Rocky Mountains.

Growth and Yield Models

Growth and yield models are classified by the spatial resolution with which they predict forest growth. The lowest level of spatial resolution is provided by whole stand models, which predict changes in conditions from stand average values. Models of this type lack the ability to predict diameter-class product information, but have the advantage of providing more precise estimates of stand volume, as described later. The model with highest resolution first predicts the growth of individual trees, and then aggregates these values into diameter classes to provide product information. Between these two extremes, a diameter distribution model assumes an underlying probability distribution to determine the numbers of stems in diameter classes.

Whole Stand Model

RMYLD2 is a computer program to predict stand-level estimates of growth and yield of even-aged and two-storied stands of five tree species in the central Rocky Mountain region. RMYLD2 is available in versions for IBM-compatible microcomputers, for U.S. Forest Service Data General mini-

computers, and for mainframe computers. An aspen subroutine for RMYLD2 provides growth and yield estimates for thinned and unthinned stands across a wide range of conditions (Edminster and Mowrer 1984). Model simulations using this subroutine have been used to explore the effect of thinning on aspen volume yield for various combinations of site quality, rotation age, and thinning intensity (Edminster and Mowrer 1984, Mowrer 1987b).

To compare models, a set of yield estimates were simulated across a range of initial stand conditions for site indices ranging from 40 to 90 feet at 80 years. Five 10-year growth projections were made, based on identical initial conditions. Figure 1a shows the gross total volume per acre estimated by the aspen subroutine to RMYLD2, with initial conditions running from left to right across the range of site indices at the front of the figure, and for five successive 10-year projections toward the rear of the figure. Projections follow an expected trend, with higher sites producing greater yields.

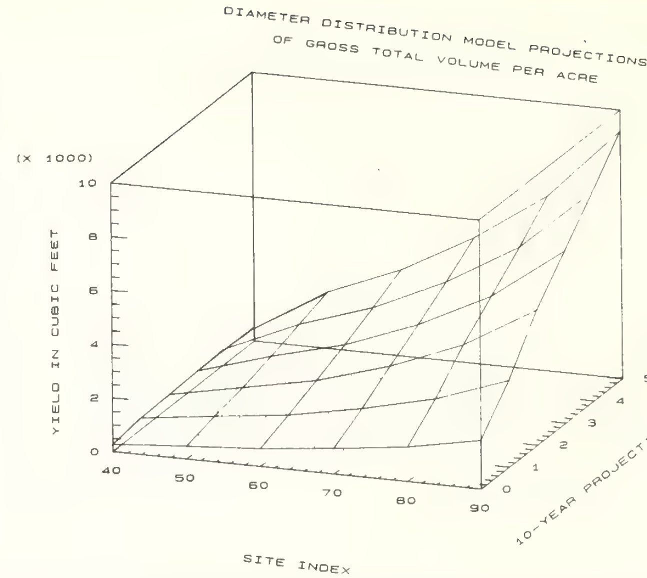

Figure 1b.--Gross total cubic foot volume per acre predicted by the diameter distribution model (ASPNORM) for the same initial site conditions.

Diameter Distribution Model

A subset of the data used to calibrate the aspen subroutine for RMYLD2 was used to develop a second growth and yield model for aspen. ASPNORM (Mowrer 1986b) predicts the growth and yield of pure, even-aged aspen stands that maintain a normal (or bell-shaped) probability distribution of stems per acre across diameter classes. Accumulation of basal area, height, and volume across these 1-inch diameter classes provides product information for aspen clones meeting the normal diameter distribution requirement.

Figure 1b shows the set of yield estimates for the diameter distribution model corresponding to those in figure 1a made by the stand average model, based on the same set of initial stand conditions. Figure 1c shows the production surfaces for both models on the same set of axes for comparison. The differences in initial volumes estimated by the two models are due to the differences in the estimation process. With increasing projection lengths, the diameter distribution model estimates less volume on lower sites than the stand average model, while for sites above 60 feet, it estimates successively more volume. When two models, based on the same calibration data as these are, provide differing results, an opportunity exists to compare the reliability of both sets of estimates.

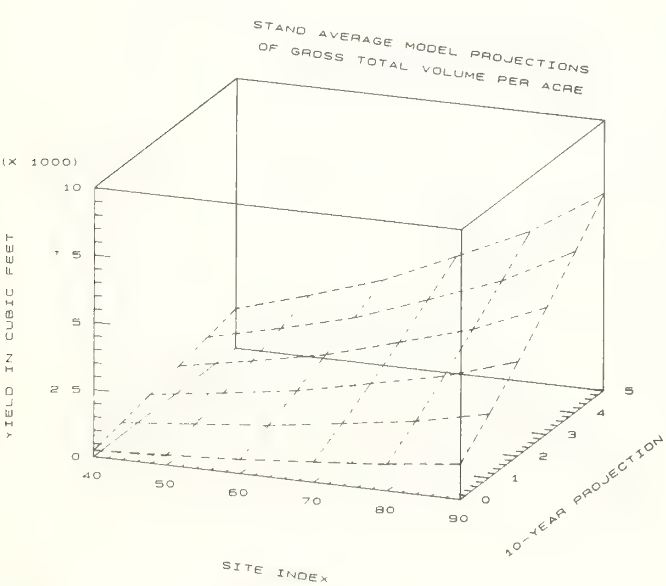

Figure 1a.--Gross total cubic foot volume per acre predicted by the whole stand model (RMYLD2) for a range of initial site conditions.

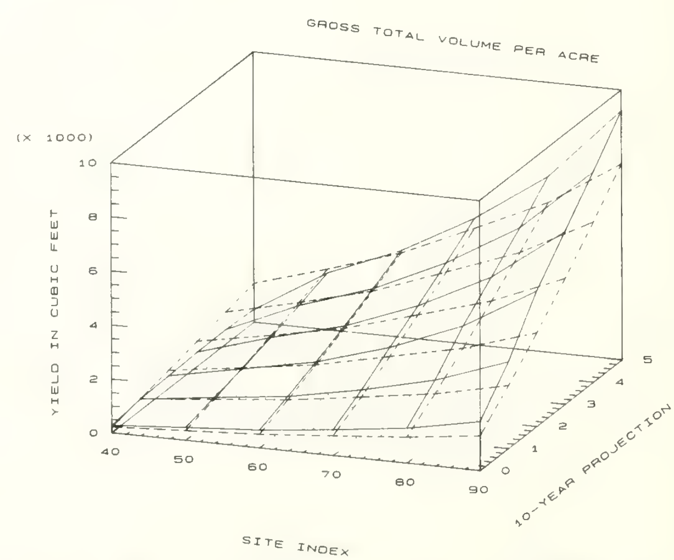

Figure 1c.--Response surfaces from 1a and 1b superimposed on the same set of axes. The diameter distribution model underestimates volume for low sites and overestimates volume on high sites with respect to the whole stand model.

Model Validation

The usual measure of reliability incorporates both bias and variance terms. Bias refers to a systematic trend in under- or overestimation of the true (but often unknown) value, while variance relates to the variability of the estimates about the true value. Model developers have addressed the bias term by comparing model predictions against repeated observations from permanent growth plots. Estimates of model bias are available for ASPNORM (Mowrer 1986b) and RMYLD2.[2]

Variance in model predictions has seldom been calculated, however. Variance in the form of sampling error is always present in forest inventory data used to initiate model projections. As repeated growth projections are made, stand variables predicted in the prior period become predictors upon which estimated values for the next period are based. Errors in predictor or independent variables accumulate in the predicted or dependent variable at each projection. Thus, errors in model variables are propagated within the model over repeated projections.

A Monte Carlo technique for estimating the variance introduced by repeated projections in growth and yield models has been developed and applied to the diameter distribution model, ASPNORM, by Mowrer and Frayer (1986) and the stand average model, RMYLD2, by Mowrer (1987a). This methodology can be adapted to provide variance estimates for growth and yield projections made by most computer models.

Monte Carlo Technique

Monte Carlo techniques involve repeated generation of random values from a known distribution. These values reflect random variations in the relationships between the variables necessary to initialize the models. Periodic model predictions represent an unknown transformation on these input variables as growth projections are made. Since this transformation is usually very complex, exact variance estimators can seldom be developed. The variance of the output variables can be estimated over a number of repetitions of the Monte Carlo process, as described in detail by Mowrer and Frayer (1986).

To provide a comparison of relative precision, an identical Monte Carlo technique was applied to both models. Appropriate input values for the diameter distribution model and the whole stand model were simulated using the Monte Carlo procedures based on the same set of plot sample data. These values are displayed graphically as initial conditions at projection zero across the front of figure 2. The cumulative means from 26 successive simulated samples from this plot provide a range of variability in input values, displayed from left to right across the front of the figure. Responses from both models are measured on the vertical axis as the coefficient of variation (the standard error divided by the mean expressed as a percent) of gross total volume calculated at each sampling intensity for initial conditions and for five resulting 10-year projections. The coefficient of variation (c.v.) provides a unitless measure of relative variability in the volume estimated by the model.

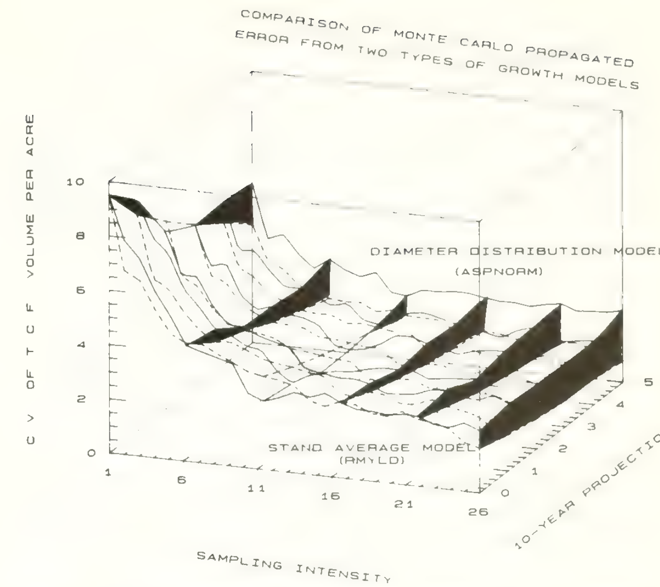

Figure 2.--Two response surfaces for Monte Carlo estimates of propagated error over five 10-year projections and increasing cumulative sampling intensity. Shaded areas represent areas where the variability in estimated gross total cubic foot volume by the diameter distribution model exceeds that of the whole stand model.

To aid in visualizing trends in relative model precision in figure 2, segments of planes passing through six levels of constant sampling intensity have been shaded where the relative variation in the gross total cubic foot volume estimated by the diameter distribution model exceeds that of the whole stand model. In general, these shaded areas increase in height with increasing projection length, reflecting greater differences in relative model precision. These results indicate that the less complex whole stand model (RMYLD2) makes more precise stand volume estimates than the more complex diameter distribution model (ASPNORM).

The advantage to this Monte Carlo method is that it can be applied externally to a model with little knowledge of the internal mechanisms of model prediction. The disadvantages are that the results are specific to the plot data used for the simulation, and that it does not include sources of error variation due to calibration errors in the regression coefficients, thereby underestimating total error.

Conclusions

The Monte Carlo results provide a basis for inferring that increases in model resolution (predicting changes in smaller units) is at the expense of model precision (the degree of certainty we may place in those predictions). We may estimate

[2]Edminster, Carleton B. 1987. Growth and yield relationships for even-aged stands of aspen in the central Rocky Mountains. Manuscript in preparation.

the distribution of diameters within a stand, but will know the resulting stand values less precisely than if they were predicted directly as stand average values. Unnecessarily increasing numbers of model estimates or the level of model resolution will contribute to increased levels of uncertainty in the resulting predictions. The implication is that resource managers should select the model that provides the information required by the decision at hand and predicts it at a level of resolution that does not unnecessarily exceed information requirements.

Just because results are printed on computer paper, the user should not assume model predictions are exact, whether they are estimates of volume per acre or approximations of associated variance. Models incorporating negative feedback to control prediction variability will appear to have less than actual error levels under the Monte Carlo simulation method. Proper interpretation of the results of this technique requires an understanding of the actual sources of estimated errors.

The Monte Carlo technique is useful not only for growth and yield models, but for virtually any model or sequence of models. This allows an assessment of the relative reliability of model projection sequences as they are incorporated into the planning process.

With the widespread proliferation of computers, it is not uncommon for several computer models to be available to predict the same phenomenon. While convenience should be considered when determining which model to use, the quality of model predictions should be an overriding concern to those making natural resource decisions. Increased model sophistication requires increased user sophistication in selecting the appropriate model for each set of circumstances.

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Application of Growth and Yield Models for Forest and Project Planning

Daniel M. Greene[1]

Abstract--This report summarizes how growth and yield models have been used for Forest and Project Planning in the Rocky Mountain Region and lists future needs of Growth and Yield Systems.

Growth and yield simulation models have been an integral part of the Rocky Mountain Region Planning Process since development of the 1975 Timber Management Plans. At that time or shortly after, the following computer programs to compute yield tables were available from the Rocky Mountain Forest and Range Experiment Station:

1. PONYLD (Myers 1971)
2. LPMIST (Myers et al. 1971)
3. SPRYLD (Alexander et al. 1975)
4. SWYLD2 (Myers et al. 1976)

These programs were designed to simulate even-aged, managed stands. They were not designed to simulate existing unmanaged stands that were already 80 to 120 years old.

In order to simulate older existing stands for development of the Timber Management Plans, the Region developed an "in-house" model; R2GROW (Greene and Gryczan 1975). R2GROW is a 2-inch diameter class model for simulating average growth of forest-wide condition classes. R2GROW was used for simulating existing stands primarily due to the capability to match inventory volumes at the start of a simulation.

In 1977, the station combined the four separate computer programs; PONYLD, LPMIST, SWYLD2 and SPRYLD into a single modular program entitled RMYLD (Edminster 1978). RMYLD was designed to simulate managed even-aged stands of mostly pure species composition and is a whole stand model.

Starting in 1979, RMYLD and R2GROW were the sole growth and yield models used for the development of the current Rocky Mountain Region Forest Plans. RMYLD was used primarily for the simulation of existing seedling or sapling stands and regenerated stands. R2GROW was used to simulate existing poletimber or sawtimber stands.

Currently the Grand Mesa, Uncompahgre, and Gunnison National Forest is undergoing a major re-analysis of their Forest Plan due to a remand by the Secretary's Office. RMYLD2, a major revision to RMYLD, is being used. The use of RMYLD2 is significant in that the user may input a percent of the stand that is stockable and average defect. RMYLD2 also includes a module for simulating the Aspen forest type.

Forest Planning

Growth and yield simulation programs have been used in the Rocky Mountain Region primarily for the development of the Forest Plans. In order to understand how these models fit into the Forest Planning Process, it is necessary to understand some of the components of the process. Major components that will be discussed are:

Forest Inventory Information

Identifying Forest Land Tentatively Suitable for Timber Production

Development of Timber Analysis Areas (Stratification)

Development of Prescriptions for each Analysis Area

Development of Yield Tables for each Prescription using RMYLD2 and R2GROW

Analysis of Alternatives and Scheduling using FORPLAN

FORPLAN Outputs that are Dependent on the Timber Yield Tables

[1]Inventory and Plans Group, Timber Forest Pest and Cooperative Forestry Management, Rocky Mountain Regional Office located in Lakewood, Colorado.

Refer to figure 1 for an overview of the Forest Planning process displaying where growth and yield models fit in. The Grand Mesa, Uncompahgre, and Gunnison National Forest Plan is currently being re-analyzed and will be used as an example of how growth and yield models are used in the forest planning framework.

Inventory

A recent inventory has been completed for the Grand Mesa, Uncompahgre, and Gunnison National Forests. Site specific inventory information from various sources is stored in R2RIS; Region 2 Resource Information System (R2 FSH 6609.21). Tree data samples (sample plot or stand data from the timber inventory) are stored on the Stand Support Tape System (R2 FSH 2409.26d). The information was combined from both sources into the RPA Data Base in order to generate Forest Inventory Tables. The system is flexible so that the information may be re-stratified as necessary to address the issues and concerns of managing the Forest. Refer to figure 2 for an overview of the inventory process.

Six products of the inventory were:

1. Full implementation of the Resource Information System (R2RIS) completed by Forest and District staff.
2. Up-to-date district stand maps completed by Forest and District Staff.

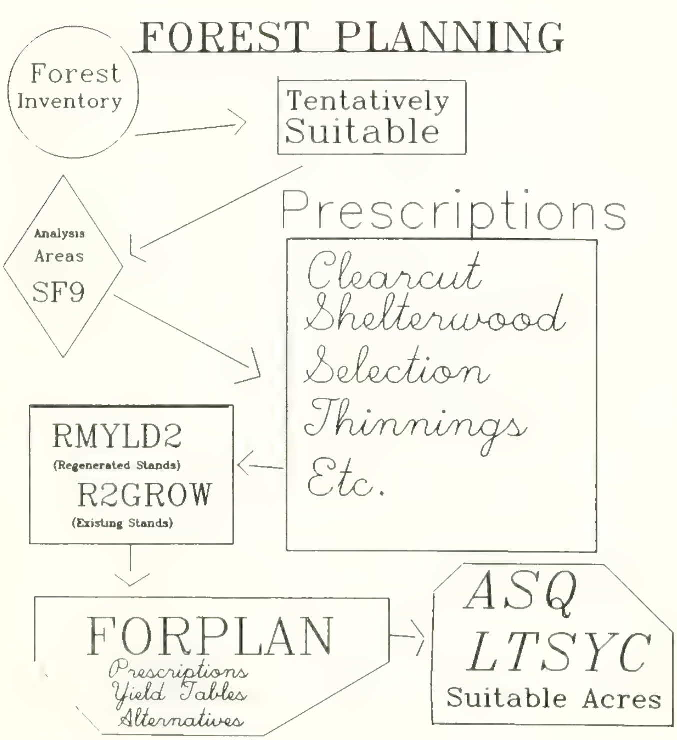


Figure 1.--Overview of forest planning process as it relates to growth and yield models.

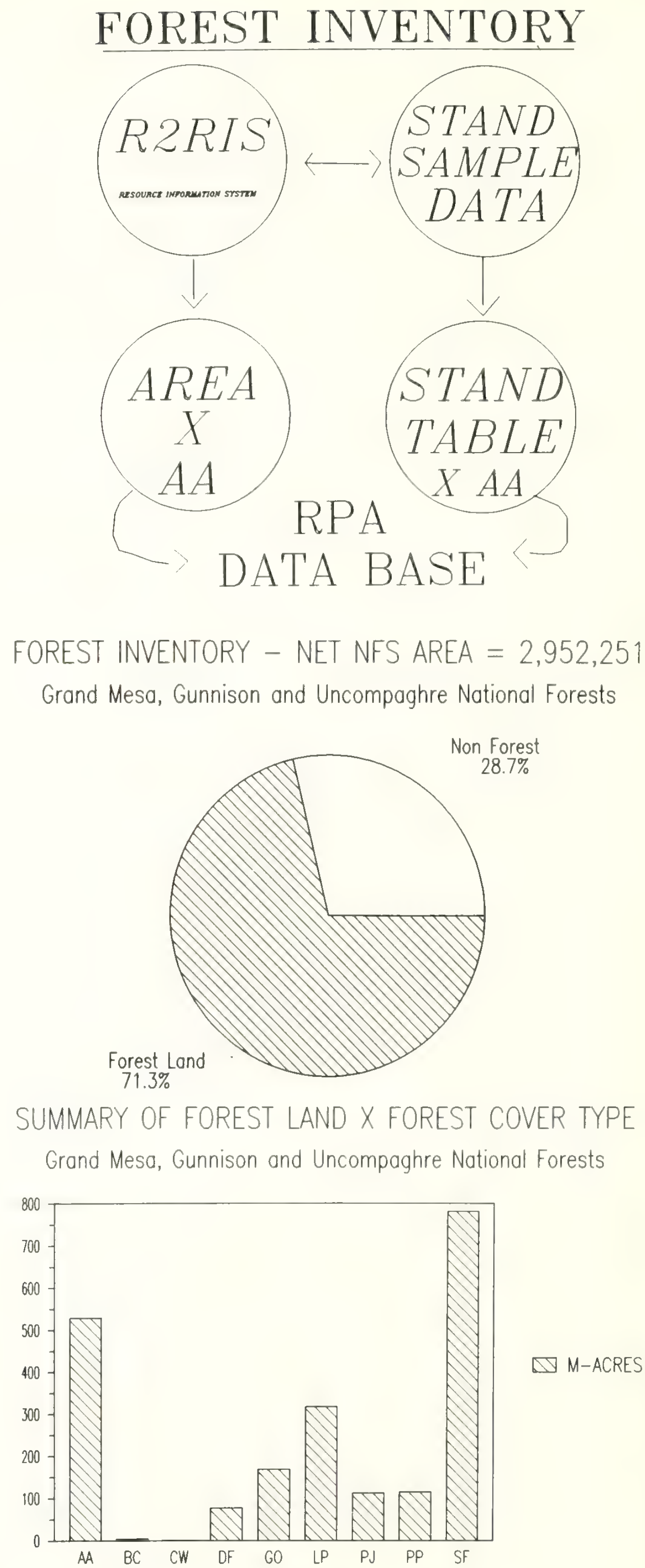


Figure 2.--Overview of the Rocky Mountain Region forest inventory process.

"All RIS sites on the Forest are currently mapped on USGS quads. The RIS maps will be the framework for all maps completed for the reanalysis." (Grand Mesa, Gunnison, and Uncompahgre NFs, Draft Addendum to Planning Action 2).

3. Per acre stand tables for each forest cover type and stand size class completed by the Regional Office.
4. A set of tables displaying total acres, total board and cubic feet volumes, etc. for each forest type and tand size class completed by the Regional Office.
5. A permanent set of field samples stored on a forest stand support tape for post stratification into forest condition classes.
6. An updated RPA data base merging per acre data from field samples with total areas from R2RIS.

The use of the R2RIS and field sample data is summarized as follows (Grand Mesa, Uncompahgre, and Gunnison, Draft Addendum to Planning Action 2, May 1987):

> "New timber inventory data will be used. This new timber data provides the site specific on-the-ground analysis required by Deputy Assistant Secretary Douglas W. MacCleery's decision on July 31, 1985. It also provides the link between the linear program allocations and multiple use benefits, which are considered later in this study.
>
> Since the Plan was issued, the "Resource Information System" (RIS) has become the standard data base for the Rocky Mountain Region. Forest Service Handbook-FSH 6609.21- displays information and coding structure for the Forest's data base. RIS provides specific resource information for each land unit or site on the Forest.
>
> RIS will be used in the analysis area (AA) identification process, for determining land not appropriate for timber production, for effects analysis, and for monitoring.

After the basic inventory tables were completed, the forest generated area totals for each timber analysis area (AA-forest cover type and condition class) from the R2RIS data base. For each of these analysis areas, a single average per acre stand table was generated from the Stand Support Tape System (Timber Inventory) using the VARGEN computer program. These average per acre tables were used as input to the Growth and Yield Models for developing yield tables for each applicable prescription.

Tentatively Suitable Lands

Part of the Analysis Area identification process is to determine lands that are tentatively suitable for the production of industrial wood products. These acres will be analyzed with the FORPLAN computer model. Yield tables need to be developed for all of the tentatively suitable acres.

> "Tentatively suitable lands, identified in accordance with the process set forth in FSH 2409.13-21, are a fixed input to the forest planning model in the establishment and evaluation of benchmarks and alternatives" (FSH 2409.13).

The following tabulation displays the tentatively suitable acres for the Grand Mesa, Uncompahgre, and Gunnison National Forests Plan Re-analysis.

Grand Mesa, Uncompahgre and Gunnison National Forests land capable, available and tentatively suitable for timber production.

Criterion	Area-Acres
Non-Forest	
-Non-forest land	837,294
-Water	10,515
Subtotal	847,809
Capable Forest Land Withdrawn From Timber Production	
-National Wilderness Preservation System	269,116
-Research Natural Areas	
(1) Gothic	
(2) Escalante	237
-Wilderness Study Area	
(1) Fossil Ridge	33,535
-Further Planning Area	
(1) Recommended Portion of Cannibal Plateau	6,801
-Administrative Sites	2,477
-Campgrounds	7,472
-Cultured Areas	400
Subtotal	320,038
Forest Land Incapable of Producing Industrial Wood	417,613
Not Physically Suited	
-Restocking within 5 years cannot be assured	8,917
-Irreversible Resource Damage	41,223
-Inadequate Response Information	1,751
Subtotal	51,891
Unsuitable Total	1,637,351
Total Net Forest Acres	2,952,251
Tentatively Suitable Land for Timber Production	1,314,900

At this point the acres of the Forest that must have associated yield tables developed using growth and yield models has been narrowed down. Refer to figure 3 for a graphic display of Tentatively Suitable Lands identified by the re-analysis of the Grand Mesa, Uncompahgre, and Gunnison National Forests.

Analysis Areas

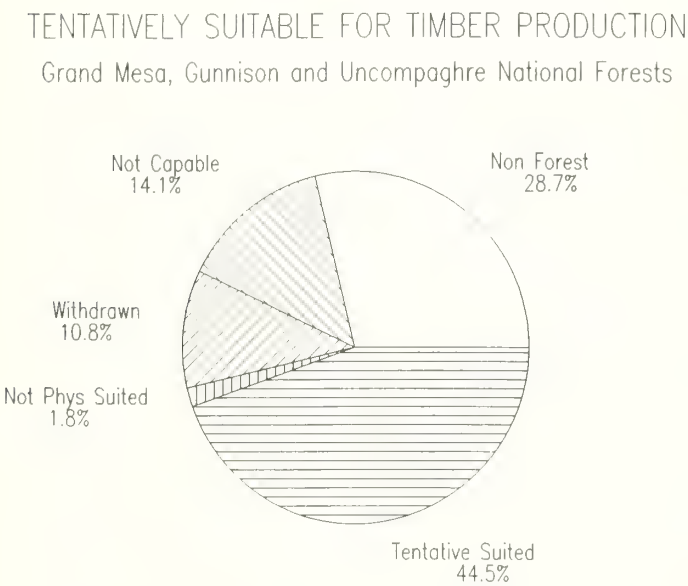
Lands tentatively suitable for timber production were subdivided into timber analysis areas. These analysis areas are expected to respond similarly to management practices in order to develop yield tables that are responsive to issues and concerns. Timber Analysis Areas defined for the Grand Mesa, Uncompahgre, and Gunnison National Forest Plan Re-analysis are:

Aspen Forest Cover Type

1. Conifer Invaded Aspen-Seedling/Sapling (MIX7)
2. Conifer Invaded Aspen-Poletimber (MIX8)
3. Conifer Invaded Aspen-Sawtimber (MIX9)
4. Predominately Aspen-Seedling/Sapling (AA7)
5. Predominately Aspen-Poletimber (MIX8)
6. Predominately Aspen-Sawtimber (MIX9)
7. Self Regenerating Aspen (SELF-R)

Lodgepole Pine Forest Cover Type

1. Nonstocked (LP6)
2. Seedling/Sapling (LP7)
3. Poletimber (LP8)
4. Sawtimber (LP9)
5. Mistletoe Infected (LPMIS)
6. Stagnated (LPSTAG)



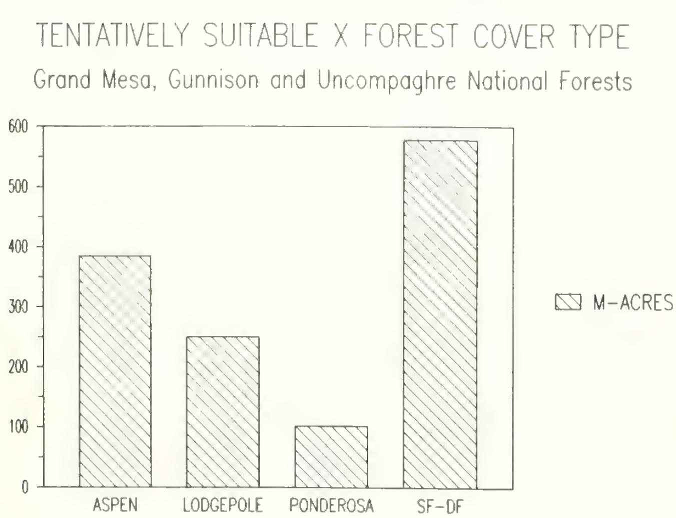


Figure 3.--Forest land tentatively suitable for timber production.

Ponderosa Pine Forest Cover Type

1. Nonstocked (PP6)
2. Seedling/Sapling (PP7)
3. Poletimber (PP8)
4. Sawtimber (PP9)

Spruce Fir and Douglas-fir Cover Types

1. Nonstocked (SF-DF-6)
2. Seedling/Sapling (SF-DF-7)
3. Poletimber (SF-DF-8)
4. Sawtimber (SF-DF-9)

Refer to figure 4 for a graphic display of timber analysis areas developed for the Grand Mesa, Uncompahgre and Gunnison Re-Analysis.

Prescriptions

Management prescriptions which could be applied to address the issues and concerns are developed for each timber analysis area.

> "Develop management prescriptions, including timber production functions, on a per acre basis for all forest land that is identified as tentatively suitable. In accordance with 36 CFR 219.27, integrate all prescriptions for tentatively suitable lands to meet one or more resource emphases and intensities for a unit of land. Complete prescription development before evaluating benchmarks and forest plan alternatives to ensure consideration of an adequate range of prescriptions in meeting forest plan objectives" (FSH 2409.13).

Each prescription is simulated using a RMYLD2 or R2GROW. Following is a sample Management Area Prescription for uneven-aged management: (Grand Mesa, Uncompahgre, and Gunnison NFs, Draft Addendum to Planning Action 2)

Management Area Prescription 7F

> Provide for uneven-aged sawtimber production on slopes less than 40%.
>
> Management emphasis is on wood-fiber production and utilization of large roundwood of a size and quality suitable for sawtimber. The harvest method by forest cover type is group selection in Engelmann spruce-subalpine fir. Release and weed occurs to harvested areas.

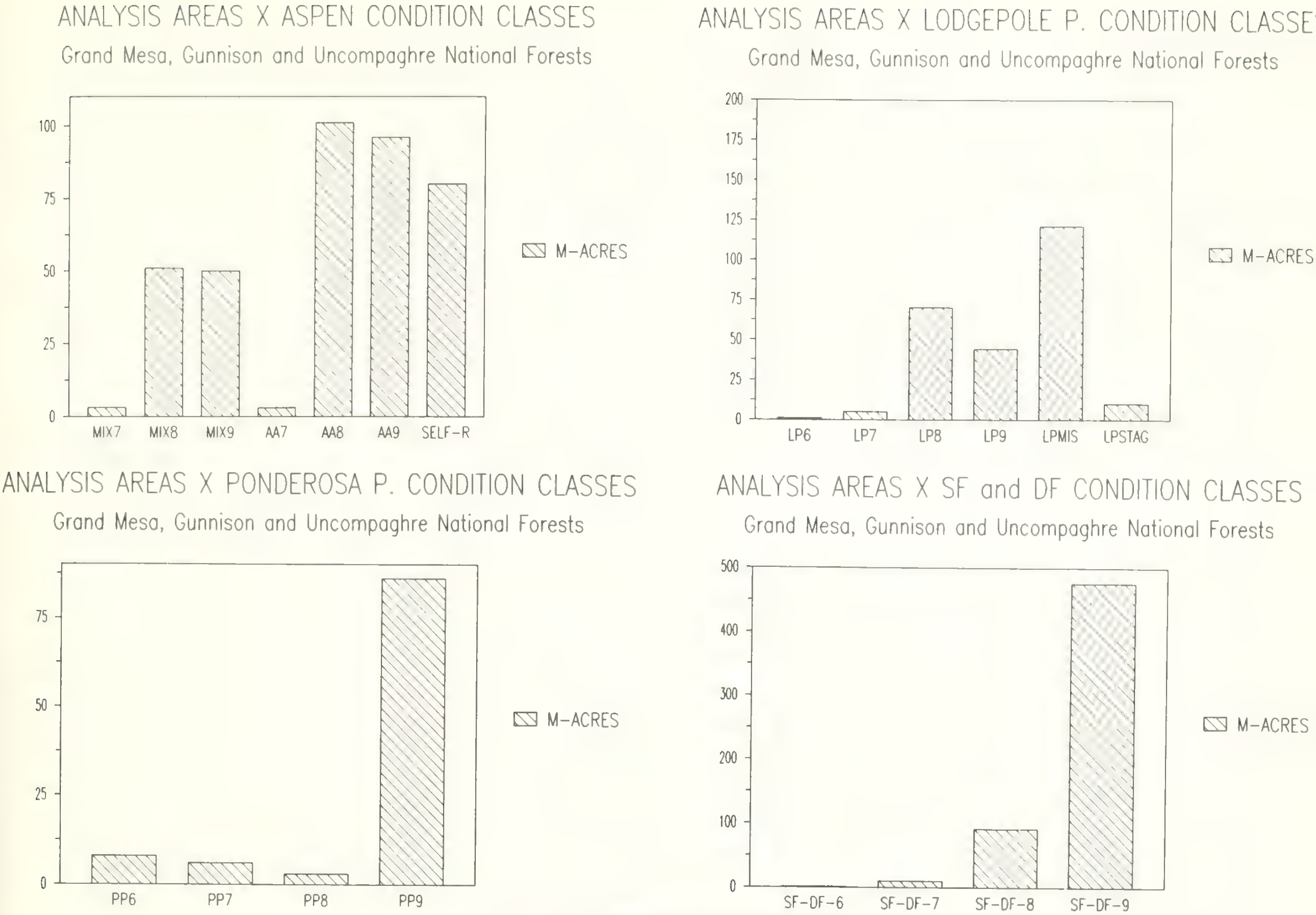


Figure 4.--Timber analysis areas.

The area generally will have a mosaic of fully stocked stands that follow natural patterns and avoid straight lines and geometric shapes. Management activities are not evident or remain visually subordinate along Forest arterial and collector roads and primary trails. In other portions of the area, management activities may dominate in foreground and middleground, but harmonize and blend with the natural setting.

Roaded-natural recreation opportunities are provided along Forest arterial and collector roads. Semi-primitive motorized recreation opportunities are provided on those local roads and trails that remain open.

Growth and yield models have to be flexible in order to simulate the different outputs expected from even-aged management versus uneven-aged management systems and thinning versus not thinning, etc. Sometimes models have to be applied that were not designed for a particular application. For example, even though RMYLD2 is an even-aged stand model, this uneven-aged system might be simulated with the assumption of even-aged groups.

Growth and Yield

The Forest Inventory field samples were stratified by timber analysis areas (timber type and condition class) to generate a single per acre stand table for each condition class. These provide the basic input for growth and yield models and the development of yield tables.

"Per acre yield tables will be developed for timber and other resources where the objective of vegetation treatment is to provide the associated multiple-use benefits. The yield tables represent production responses to management activities for such resources as range, timber, wildlife, recreation, and water" (Grand Mesa, Gunnison, and Uncompahgre, Draft Addendum to Planning Action 2, May 1987).

In general, R2GROW is used for older existing stands and RMYLD2 is used for regenerated stands or younger established stands. However this is not a "hard and fast" rule since sometimes RMYLD2 is used for mistletoe infected older existing stands, etc. Several different prescriptions and harvest methods may be modeled for each analysis area. Refer to figure 5 for a generalized flowchart of the use of growth and yield programs in the Rocky Mountain Region's forest planning process.

Each prescription for timber analysis areas is modeled using R2GROW or RMYLD2 to develop per acre yield tables for timber and other outputs to be used in FORPLAN (Forest Planning Model). The yield tables developed for the regenerated stands using RMYLD2 focused on the vegetation cover type since condition class is not as much of a factor for regenerated stands. A single regenerated stand table is used for several existing stand conditions. Refer to figure 6 for an example yield table generated by the RMYLD2 program.

Forplan

FORPLAN is the computer model that was used for the development of most of the current Forest Plans.

> "The Forest Planning Model (FORPLAN) will be the required primary analysis tool for the Forest Plans. The FORPLAN model is a linear programming package for resource allocation and activity scheduling, with linkages to program planning." (USFS Washington Office letter of December 3, 1979, file designation 1920).

Timber, range and other vegetation analysis areas are further refined by other identifiers relating to issues, concerns and opportunities prior to FORPLAN analysis:

> "Each analysis area will be defined by six levels of attributes with respective categories. Each land unit or site displayed in the resource date base (RIS) will be assigned to a specific analysis area based upon that land unit's unique characteristics. The analysis area acres are an aggregation of the acres of each land unit from the data base (RIS)." (Grand Mesa, Uncompahgre, and Gunnison, Draft Addendum to Planning Action 2, May 1987)

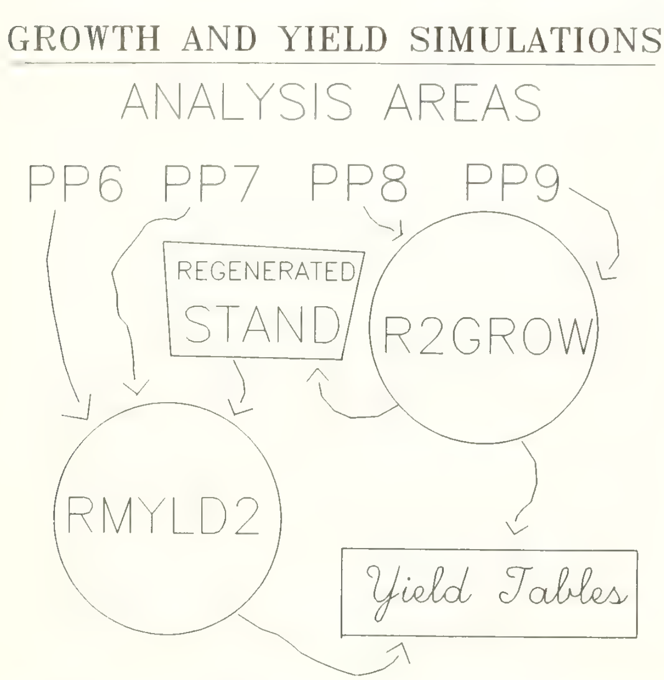


Figure 5.--Overview of the use of RMYLD2 and R2GROW for forest planning in the Rocky Mountain Region.

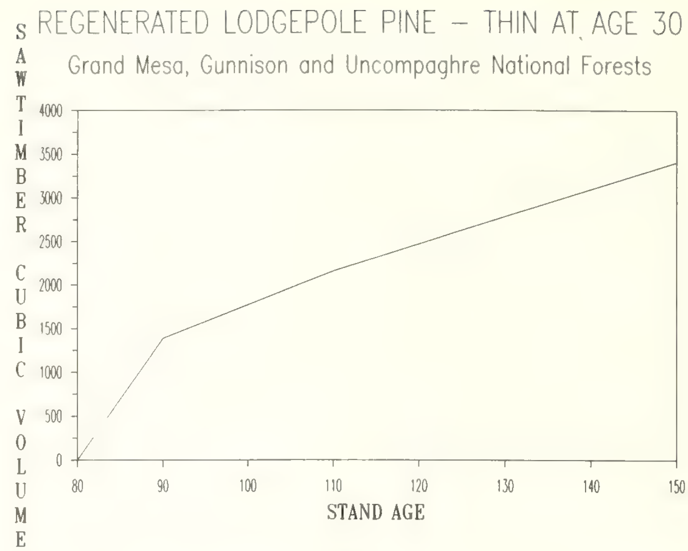


Figure 6.--Sample yield table generated by RMYLD2. Precommercial thinning and clearcut in the lodgepole pine forest type.

The six levels of analysis area identifiers are Proclaimed Forest, understory condition of forage for livestock, slope class, road access, vegetation cover types, and vegetation condition class.

The following R2RIS data base components are considered necessary for the re-analysis and the ones flagged with and asterisk (*) were used to define FORPLAN analysis areas (Grand Mesa, Uncompahgre, and Gunnison, Draft Addendum to Planning Action 2, May 1987):

Component Name	Description
Location	Map and data base identifier
Site	Map and data base identifier
Area Acres	Area of each site (stand)
*Slope Percent	Describes the majority of site
Aspect	Direction the site faces
Elevation	To the nearest 100 feet
Watershed	Identifies watershed site is in
County	County site is located in
*Ownership	National Forest admin., etc.
*Land Use Class	Forest land, nonforest land, water
Special Kind	Wilderness, Non-Wilderness, etc.
Special Unit Codes	Big Blue Wilderness, etc.
Range Allotment	Range Allotment site is in
*Range Component	Range suitability and type
Timber Component	Timber suitability
Recreation Opportunity Spectrum	ROS Classes (inventoried)
Visual Quality Objective	VQO Classes (inventoried)
*Game Range Type	Summer & Winter Range
Other Site Types	Administrative Site, etc.
*Road Access Class	Miles
*Range Condition	Ecological Condition
*Range Trend	Ecological Trend
*Forest Type	Spruce/fir, Lodgepole Pine, etc.
*Stand Size Class	Sawtimber, poletimber, etc.
*Mistletoe	Mistletoe Infection Rating
*Forest Option Field	Forest Condition Classes

Forplan Outputs

Yield tables are used in the model depending upon prescriptions and alternatives selected by the model. The FORPLAN outputs mostly related to the growth and yield projections are Allowable Sale Quantity (ASQ), Long Term Sustained Yield Capacity (LTSYC) and the final suitable acres. ASQ is defined as follows:

> "The quantity of timber that may be sold from the area of suitable land covered by the Forest Plan for a time period specified by the plan. This allowable sale quantity (ASQ) is usually expressed on an annual basis as the average annual allowable sale quantity." (FSM 1900)

LTSYC is defined as follows:

> "The highest uniform wood yield from lands being managed for timber production that may be sustained, under a specified management intensity, consistent with multiple-use objectives." (36CFR 219.3)

> "... a quantity which can be removed from such forest annually in perpetuity on a sustained-yield basis ..." (National Forest Management Act of 1976)

Table 1 displays timber outputs for the current Forest Plans in the Rocky Mountain Region.

Project Planning

Projects plans are tiered to the Forest Plan and implemented based on the Forest Plan Implementation Schedule. Project plans are not another level of planning, but instead an extension of the Forest Planning Process with more detailed site specific data available for the project area in consideration.

Table 1.--Rocky Mountain Region forest plans.[1]

	Suitable Acres	Average Annual ASQ	Average Annual ASQ	Average Annual LTSYC	Average Annual LTSYC
	(M-acres)	(MMCF)	(MMBF)	(MMCF)	(MMBF)
Arapaho/Roosevelt	360	7.4	28.4	16.2	62
Gm/Unc/Gun	476	7.0	35.0	21.0	105
Pike/San Isabel	582	7.6	25.7	12.8	43
Rio Grande	465	7.2	36.1	17.5	88
Routt	381	7.7	36.4	12.2	57
San Juan	470	10.2	40.7	19.2	77
White River	473	5.3	25.2	27.3	131
COLORADO	3207	52.4	227.5	126.2	563
Bighorn	266	3.9	15.1	7.6	29
Black Hills	1034	35.1	152.1	40.0	173
Medicine Bow	448	5.9	28.4	16.9	81
Shoshone	86	2.5	11.2	3.5	15
WYO./S. DAK.	1834	47.4	206.8	68.0	298
REGION 2	5041	99.8	434.3	194.2	861

[1] "Forest Plan Timber Facts," U.S. Forest Service, Rocky Mountain Region, April 8, 1987.

PROJECT PLANNING

FOREST PLAN

IMPLEMENTATION SCHEDULE

INVENTORY

(R2RIS STAND EXAM)

ANALYSIS AREAS

ALTERNATIVES

OUTPUTS

(SIMULATIONS OR CANNED)

ENVIRONMENTAL ANALYSIS

Figure 7.--Overview of the use of growth and yield models for project planning in the Rocky Mountain Region.

Even though more data is available, growth and yield simulations are generally not done to the level of precision that they were for the Forest Plans. Often, "canned" growth and yield simulations are referred to such as the "Book Process" (Managing Forested Lands For Wildlife, Colorado Division of Wildlife, 1984), or runs previously made representing various condition classes on a District or Forest.

In any case, alternatives are tested and outputs are based on current or past growth simulations and an Environmental Analysis is always made which will result in one of three documents:

1. Environmental Impact Statement
2. Environmental Assessment
3. Categorical Exclusion

Refer to figure 7 for a diagram of the project planning process.

Growth and Yield System Needs

The existing growth and yield models have been used for the current round of Forest Planning, but are weak in many areas (fig. 8). RMYLD2 cannot simulate uneven-aged stand structures, mixed species stands or long rotation ages. In addition, it is difficult to match the inventory of existing stands using RMYLD2. R2GROW cannot handle mixed species stands or long rotation ages, and is not capable of simulating regenerated stands. R2GROW also lacks research validation and is currently out-dated.

For the future, we need a complete growth and yield system for the Rocky Mountain Region (Region 2 & Rocky Mountain Station Forest Growth and Yield System Development and Implementation Plan, February 13, 1985). This plan includes phasing out R2GROW and replacing it with a new model built by the Rocky Mountain Forest and Range Experiment Station. This new model will be a Generalized Growth and Yield Model (GENGYM). GENGYM is proposed to be a 1-inch diameter class model designed to simulate growth and yield of even-aged, uneven-aged, and irregular structured forest stands of pure or mixed species composition.

RMYLD2 is expected to still have use in the future since it is a whole stand model and is more economical and efficient than a diameter class or individual tree model for some applications. In addition, RMYLD2 simulations can be made based on data that is stored in the R2RIS data base. Data requirements for diameter class (e.g. GENGYM) or individual tree models (e.g. PROGNOSIS) require the use of tree data files (Forest Inventory Field Sample Data).

Refer to figure 9 for a summary of the Rocky Mountain Region needs for a complete growth and yield system that will handle mixed species and uneven-aged management.

One of the needs listed is to monitor the results of models; "Do we really get the expected results from thinning that were simulated?" Where thinning occurs will be tracked in the R2RIS data base. However, a monitoring plan for the expected growth increases, mortality losses, etc. for planned treatments has not been designed for the region. This would probably involve the use of permanent plots established in areas before and after treatments which are expensive. We have the tools to measure many types of permanent plots and store data, but they are currently being utilized for continuous inventory samples which are not established to reflect various treatments.

Summary

Growth and Yield models play an important role in the Forest and Project Planning Process. Without them various prescriptions and alternatives cannot be adequately tested. Many of the alternative outputs in the development of the Forest Plan are directly related to the models such as Allowable Sale Quantities, or Long Term Sustained Yield Capacities.

There is still a long way to go in the development of models. Model results have not been monitored, current models do not display statistical variances for each simulation period, and most models are weak in estimating mortality. Before models are used to any great extent for Project Planning they will have to become more "user friendly." Most current models were built for the Fort Collins Univac Computer.

LIMITATIONS OF EXISTING MODELS

RMYLD2
(Whole Stand Model)

— Unevenaged Stand Structures

— Mixed Species Stands

— Long Rotation Ages

— Match Existing Stand Inventory

R2GROW
(Diameter Class Model)

— Mixed Species Stands

— Long Rotation Ages

— Regenerated Stands

— Research Validation

Figure 8.--Limitations of R2GROW and RMYLD2.

GROWTH AND YIELD SYSTEM NEEDS

Capability to Project the Development of Stands in All Forest Cover Types

Provision for Updating Existing Inventories

Simulation of Both Even and Unevenaged Silvicultural Systems

Simulation of No Action as Well as Applicable Management Alternatives

Simulation of Natural, Noncatastrophic Mortality, Bark Beetle Mortality, and Growth Loss from Defoliation and Diseases

Accounts for Establishment of Natural Regeneration

Simulation of Either Individual Stands or Stratum Averages

Compatibility with Stand Data Collection and Printout

Allow for Different Merchantability Standards

Provide Linkage to Other Output Models

Monitoring

Figure 9.--Rocky Mountain Region needs for a complete growth and yield system.

For systems to be responsive to the needs of District Foresters they need to be re-written for the Data General Computers (DG) currently installed in District Offices or for personal computers (PC).

The RMYLD2 program has been modified to run on a "Personal IBM compatible computer" or the "Data General Computer" by the Rocky Mountain Forest and Range Experiment Station. GENGYM will be developed strictly for the "DG" or "PC." It is expected that this is the direction growth and yield models will take in the future.

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Trees--The Link Between Silviculture and Hydrology

Merrill R. Kaufmann, Charles A. Troendle, Michael G. Ryan, H. Todd Mowrer[1]

Water and timber are forest products that result from complex processes at the watershed, stand, and tree levels. Subalpine forest ecosystems, which are considered here to be equivalent to stands or small catchments, receive inputs of energy, carbon, water, and nutrients. Within the ecosystem, a wide array of processes involves conversions and exchange of these components. The net result of these processes and transformations affects the quantity of water available for streamflow and biomass production, including merchantable bole volume.

The study of processes involved in water and biomass production from subalpine forest ecosystems often requires research on isolated components of the ecosystem. Yet, an understanding of ecosystem behavior also requires that all the components be considered together, because all of the processes and components of the ecosystem interact to produce the observed outputs.

Trees play a crucial role in ecosystem behavior, because a major portion of energy, carbon, water, and nutrient exchange in ecosystems are influenced by or occur in trees. At the level of forest stands, for example, the canopy intercepts energy and influences air movement, thereby affecting photosynthesis, transpiration, and the thermal and light environment of the forest stand. An existing stand represents the current status of competition for energy, water, and nutrients.

At the level of foliage, carbon is fixed by photosynthesis, some of it stored in wood or other portions of the biomass until harvest or death, some utilized for foliage or fine roots having a shorter lifetime than that of the tree, and some utilized in respiration. Also in foliage, water absorbed by tree roots is transpired and returned to the atmosphere as vapor. And finally, nutrients continually are absorbed and used for growth or returned back to the forest floor by foliar leaching or loss of plant tissue.

The gas exchange processes of the foliage provide one link between silvicultural and hydrologic phenomena. CO_2 enters foliage through stomata, and water leaves the foliage through the same stomata (fig. 1). Thus, dry matter production, the essence of timber productivity, and transpiration, a major component of the hydrologic cycle, are simultaneously dependent on stomatal behavior. This paper focuses on how trees influence various aspects of the water and carbon cycles, and discusses how tree processes are involved in subalpine forest hydrology and silviculture.

Papers by Smith, Meiman, and Troendle and Kaufmann (this volume) discuss related aspects of silviculture and hydrology of subalpine forests in the central Rocky Mountains. Stottlemyer addresses the trends in input/output chemical balances of the Fraser Experimental Forest watersheds.

TREES AND THE CARBON CYCLE

Carbon fixation by trees is the sole source of dry matter for wood production, except for very minor amounts of nutrients found in woody material. While photosynthesis by the understory vegetation may be substantial in some forest types and may be important in forage production, it does not contribute to commercial wood production.

Carbon fixation depends upon a number of factors. There is reasonably good evidence that, for young stands, biomass productivity is nearly linearly related to interception of radiation (Linder 1985). Radiation interception is dependent on day length, slope and aspect, shading by competing vegetation, and the arrangement of foliage within a crown. For a given physiographic location, optimal stand productivity depends upon the canopy being configured in a way that maximizes light interception while guarding against the negative effects of over-crowding, which may lead to carbon allocation away from harvestable product. Silvicultural research (e.g., Alexander 1986a, 1986b; Alexander and Edminster 1980, 1981) has been conducted to maximize timber productivity using an empirical approach to density control that effectively optimizes radiation interception for a given site.

The volume growth of a tree depends not only upon how much energy the tree crown captures and upon factors affecting photosynthesis through effects on stomatal behavior, but also on the allocation of the newly fixed carbon. Within trees, carbon may be allocated to stem dry matter production, replacement of foliage and fine roots, or maintenance respiration. The "harvest index," the proportion of stemwood to total tree biomass, is one measure of long-term effects of annual carbon allocation. Waring and Schlesinger (1985)

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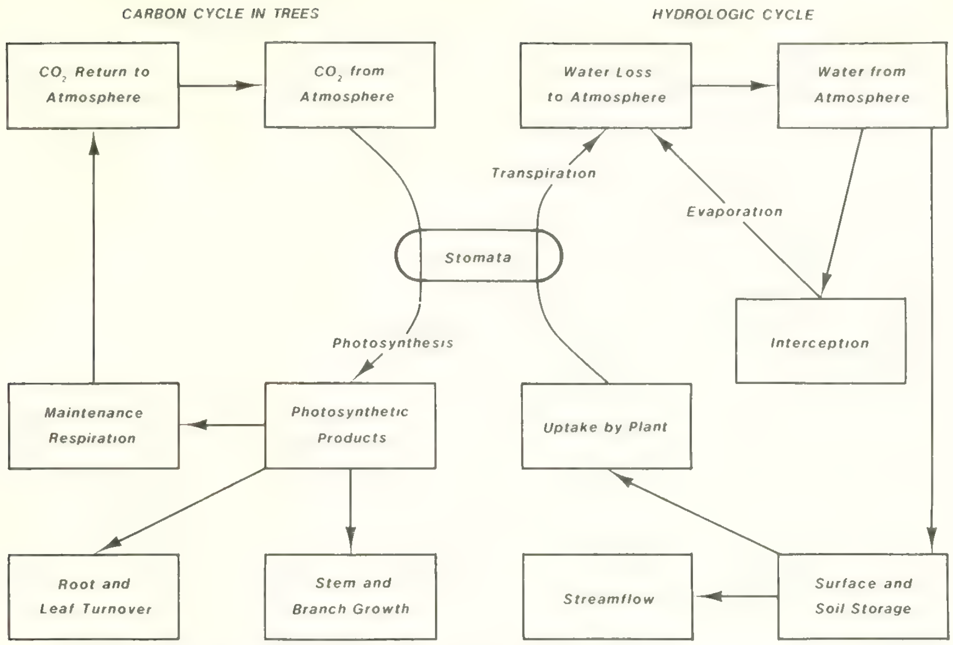

Figure 1.--Simplified carbon and hydrologic cycles. Photosynthesis and transpiration involve the exchange of CO_2 and water vapor through stomata.

hypothesize that there is a hierarchy of priority for receiving newly fixed carbon, and stemwood is generally produced only after demands by foliage and fine roots have been met. An understanding of allocation processes therefore may help determine how management practices can alter the harvest index.

Kaufmann and Ryan (1986) examined the growth rate of individual subalpine conifer trees. They determined that volume growth is influenced by energy capture, which is a function of leaf area, but concluded that other factors also were important. Their data showed that the growth efficiency of trees (volume growth per unit absorbed radiation) was different among species and varied with tree age. Efficiency was notably different between lodgepole pine, an intolerant species, and Engelmann spruce and subalpine fir, both tolerant species (fig. 2; also see Ryan, this volume). The growth efficiency of pine was much higher during the first 100 years than that for spruce and fir, but it declined to the spruce-fir levels in about 200 years.

It may be hypothesized that tree volume growth and growth efficiency depend, in part, upon the amount of new photosynthate that is utilized in maintenance respiration, and that the maintenance respiration requirements depend on the respiratory biomass existing in the tree. Ryan (this volume) reports that the amount of sapwood supported per unit leaf area varies among species, and he is currently conducting studies on the sapwood respiration rates of pine and spruce of varying sizes and ages. These studies may be helpful in reaching an understanding of the balance and allocation of carbon in subalpine conifers, and they may provide a basis for evaluating limitations of growth caused by inadequate water or nutrient availability.

There is increasing evidence (Grier et al. 1981, 1982; Linder and Axelson 1982) that fine root production represents a major sink for newly fixed carbon. Fine roots (including fungal symbionts) are very important for both water and nutrient uptake, and aboveground production may depend more on how such carbon is used by fine roots than on differences in assimilation. Thus, silvicultural practices, such as thinning and fertilization, may increase the harvest index because of decreased allocation to fine root production rather than increasing net assimilation.

Current empirical prediction models provide estimates of timber and water production on a par with our present ability to measure them. While empiricisms are seldom the best possible estimators of tree or stand performance and interaction, estimators specific to each microprocess within a tree are likely to involve too much inherent variability for accurate prediction when aggregated to a stand level. Knowledge of carbon balance and carbon allocation in subalpine species is very limited, however. Additional research on the carbon cycle in subalpine trees may refine our understanding of the effects of stand structure, site, and environmental conditions on tree growth. Enhanced knowledge of these microprocesses within the tree and their effect on macroprocesses within the ecosystem will certainly provide guidance to improve predictive relationships at the tree and stand level.

TREES AND THE HYDROLOGIC CYCLE

The hydrologic cycle of an ecosystem includes water input as precipitation (snow or rain), movement within the ecosystem (often involving a change of phase from snow to liquid water and from liquid to vapor), and output in the forms of

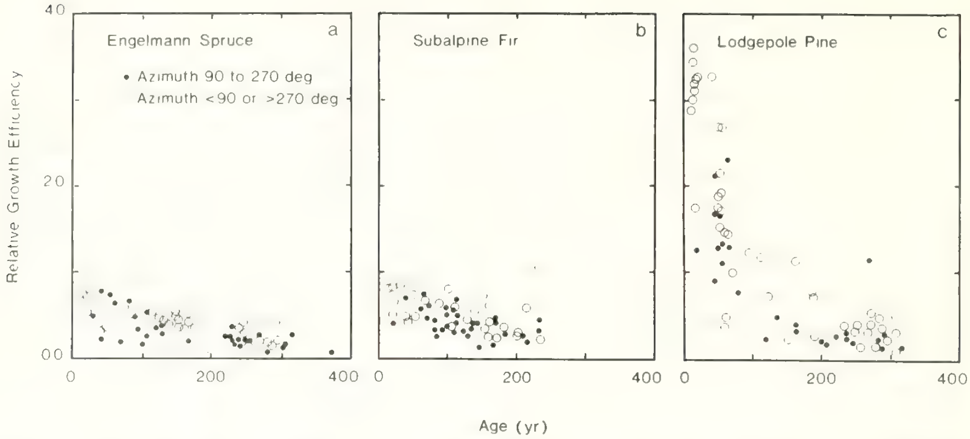

Figure 2.--Relative growth efficiency as a function of tree age and aspect of the site for (a) Engelmann spruce, (b) subalpine fir, and (c) lodgepole pine. The relative growth efficiency is a measure of tree volume growth in relation to potential absorbed radiation.

water (streamflow) or water vapor (evapotranspiration or ET). Associated with the movement of water is the movement of chemicals, both those entering and leaving the ecosystem and those cycling within the ecosystem. Trees absorb water and nutrients from the soil. Through transpiration they release water to the atmosphere, and through foliage leaching and foliage and root turnover they release some nutrients to the soil and litter. Trees also intercept significant quantities of water that evaporates without entering the soil-plant system, and they intercept chemicals from the atmosphere, both in precipitation and as dryfall.

Streamflow from forested ecosystems depends upon the total precipitation received and the amount lost from the unit as ET, plus any amount that percolates directly into the groundwater supply. Trees have a direct influence over the amount of precipitation input available for streamflow, because they (1) transpire water, (2) intercept water that is evaporated or sublimated directly back to the atmosphere, and (3) modify the understory ET environment.

Water yield from subalpine forests in the central Rocky Mountains is very important in the West, and considerable attention has been given to the effects of stand management on water yield from subalpine watersheds. Many studies have indicated that the annual yield of water may be increased by stand manipulation. Three watershed experiments in Colorado have demonstrated increased water yield after harvest (Wagon Wheel Gap, Fool Creek, and Deadhorse Creek--see Troendle 1983). The Fool Creek experiment continues to demonstrate increased streamflow more than 30 years after harvest. Furthermore, calculations based on time-series analysis of the decline in increased streamflow, on the decline in winter snowpack accumulation, and on projected increases in tree leaf area index (LAI) in the harvested areas, all indicate that the increase will not totally disappear (return to pretreatment streamflow) until 70 to 80 years after harvest (Kaufmann 1985a, Troendle 1983, Troendle and King 1985).

Most effects of stand manipulation on water yield may be attributed to effects on total annual ET, because the gross annual precipitation and percolation to groundwater (if any) are not likely to be affected by stand density. In a review of the use of forest management techniques to increase the yield of water from subalpine forests, Troendle (1983) provided evidence indicating that water yield augmentation resulted from stand harvesting effects on both summer ET and winter snowpack accumulation. Meiman (this volume) reviews evidence that the snowpack water equivalent in harvested watersheds is increased because of a reduction in sublimation when stands are thinned or clearcut. Troendle and Kaufmann (this volume) address the effect of stand density on both total annual water yield and on growing season soil water depletion rates.

Annual ET of subalpine forests has several components. Variation in these components through the year and as a result of stand manipulation makes ET both dynamic and very complex. During the summer months when no snow exists, stand ET includes overstory transpiration, understory transpiration, and evaporation of water intercepted by the vegetation and the litter and soil. During the winter, stand ET is composed primarily of evaporation from the snowpack and evaporation of snow intercepted by the forest canopy. The generally frozen conditions prevent transpiration by the trees. During the transition periods of spring and autumn, transpiration by the overstory varies widely with weather conditions. Snow cover during these periods is incomplete or transient, and ET beneath the overstory occurs as evaporation from the snowpack and litter, transpiration from the understory vegetation, or both. Interception losses during this period include evaporation of both rain and snow.

Summer ET

The principal pathways of water loss for the overstory, understory, and ground are shown in figure 3. Each compo-

nent of summer ET is influenced by the type and structure of the forest stand occupying a site. Most evidence suggests that during summer months, ET in the subalpine forest exceeds precipitation and results in a moderate soil water deficit. Troendle (1987) recently showed that in an uncut area, soil water depletion exceeded summer precipitation, resulting in soil water deficits. Flow into a subsurface collection system at the base of a forested slope occurred only in the spring after snowmelt satisfied recharge requirements. Recharge requirements on a nearby clearcut plot were substantially less. Subsurface outflow from the clearcut occurred after a significant summer rainfall or in early autumn when ET was reduced, indicating that 1% or 2% of the summer rainfall may directly become streamflow following timber harvest.

These results illustrate the importance of the forest canopy in affecting summer ET. A forested site utilized both summer precipitation and some of the water stored in the soil, resulting in soil water depletion during the summer months. In an unforested site, however, the understory vegetation utilized much less of the stored soil water, resulting in a 2.5- to 3-inch (6- to 8-cm) reduction in soil water depletion. This allowed large storms during the summer and precipitation in the autumn (when ET demands were lower) to create a surplus, resulting in outflow from the clearcut. Since more than 95% of the measured flow increases occur during the spring snowmelt period, the subtle growing season changes observed at the plot level are not easily detected at the watershed level. However, Troendle and Leaf (1980) noted that flow increases can occur any time precipitation input (rain or snowmelt) exceeds the recharge requirements in the cutover area (also addressed in Troendle 1983).

Overstory Transpiration

Overstory transpiration is directly related to the atmospheric evaporative demand, but it also is influenced by LAI and stomatal behavior (Kaufmann 1984a, Kaufmann and Kelliher in press). At equivalent stand basal areas, LAI varies greatly depending on the species composition of the stand (Kaufmann et al. 1982). Furthermore, stomatal behavior also varies among species, such that for equivalent environmental conditions and basal areas, stands of different species may have widely different tree transpiration rates (Kaufmann 1985b). Physiographic characteristics of the site (slope, aspect, and elevation) also influence overstory transpiration through effects on light, temperature, and humidity within the forest canopy.

Understory ET

Overstory stand density and species composition also may affect understory ET. Differences in transmission of irradiance by the overstory affect how much energy is available at the forest floor for understory ET. Light transmission of subalpine forest stands is a function both of LAI and of leaf area clumping within crowns (unpublished data, Oker-Blom, Ryan, and Kaufmann). At equal stand densities, the LAI for lodgepole pine and aspen stands is considerably lower than for Engelmann spruce-subalpine fir stands. Differences in light transmission to the forest floor may influence the understory species composition and vegetation density, as well as the environmental conditions regulating ET.

Overstory density and structure affect aerodynamic mixing in the forest stand, and this may affect ET processes. Most

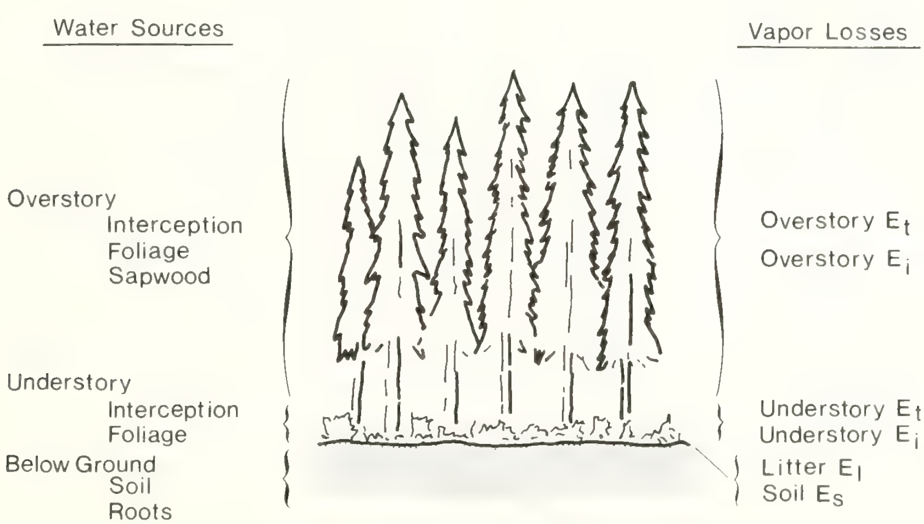

Figure 3.--Water sources and avenues by which water vapor is lost from a forest. Evapotranspiration (shown here as E) may occur through transpiration (subscript t) from the overstory and understory vegetation, through evaporation of intercepted water (subscript i), and through evaporation from litter and soil (subscripts l and s).

evidence suggests that air in the overstory of conifer stands is well mixed, and as a result transpiration is regulated primarily by stomata and the vapor gradient (Jarvis 1985, Kaufmann and Kelliher in press). Lower in the canopy, however, mixing is poorer. As a result, the microenvironmental conditions existing at the understory level depend much more on the radiation environment than they do in the overstory. This is evidenced by the much warmer temperatures of air and soil on south-facing slopes than on north-facing slopes during midday (Noble and Alexander 1977), even though canopy temperatures of the overstory seem to be relatively unaffected by radiation input (Kaufmann 1984b). Furthermore, canopy density and the related aerodynamic mixing may differ with aspect, with north aspects typically having a more dense overstory than south aspects.

As a consequence of these overstory effects on the distribution of radiation and on aerodynamic mixing, the density and structure of the overstory may play an important role not only in affecting overstory transpiration, but also in regulating understory ET. While data are not available, it is quite possible that tree harvesting techniques that result in different patterns of leaf area distribution in the overstory (i.e., partial harvest versus patch cutting) could alter understory ET even though they result in the same total residual stand LAI.

Interception

Rainfall interception by the overstory is affected by the size and duration of storm events, but interception depends as well upon the surface area on which water can accumulate. Wilm and Dunford (1948) measured precipitation in openings and beneath lodgepole pine stands of varying density and observed interception losses by the overstory of 7% to 32% of precipitation during July, August, and September. Reynolds and Knight (1973) observed that throughfall was 79% of precipitation for four lodgepole pine stands, compared with 60% for four spruce-fir stands (equivalent to interception rates of 21% and 40%). Interception in both of these studies appeared to be positively correlated with LAI.

Interception by the understory and litter also prevents rainfall from reaching the rooting zone of the trees. Reynolds and Knight (1973) observed that the water-holding capacity of litter was about 125% of the litter dry weight in both lodgepole pine and spruce-fir types. It also is possible that, in harsh sites where mineral soil is exposed, intercepted water in the upper few centimeters of soil may be unavailable to trees because the absorbing roots are deeper under these conditions.

Off-Setting Conditions

It is clear from this discussion that a number of factors, which may vary naturally or as a result of management activities, can affect the ET processes occurring during the transpiration season. It also is obvious that changes in stand structure and composition may have complex effects on ET, because several components of ET may be changed.

Considering overstory transpiration alone, transpiration apparently is affected by LAI, and it varies widely among species at the same stand basal areas (Kaufmann 1984c, 1985b). But within a species, a change in stand density and LAI influences interception of precipitation by the overstory, the transmission of light to the understory, and perhaps water availability for growth and transpiration by understory vegetation. Similarly, the differences in LAI among species at similar stand densities may affect interception and understory ET processes.

For example, the understory vegetation beneath spruce-fir stands is often fairly sparse, whereas beneath aspen stands the vegetation is frequently dense and lush. Estimated branch transpiration rates for aspen were considerably lower that those for spruce-fir, suggesting that less soil water was extracted by aspen than by spruce-fir (Kaufmann 1985b). However, the aspen measured were in mixed stands rather than in pure stands. In pure stands, a well-developed aspen understory may use considerably more water in ET than a spruce-fir understory because of higher light transmission, better development of the vegetation, and higher availability of soil water. Consequently, some of the savings by the aspen overstory may be offset by increased losses from the understory. Limited data from the Fraser Experimental Forest indicate soil water depletion rates under various densities of aspen are similar to those under similar densities of lodgepole pine.

As another example of the complexity of relating total ET to stand conditions, a reduction in basal area by partial harvest versus patch cutting may be considered. When LAI is reduced over an entire stand by uniformly distributed tree harvesting, light transmission to the forest floor increases, favoring increased ET from the forest floor. In a clearing created by removal of the same basal area in patches, the exposed forest floor receives the entire radiation input and probably has higher aerodynamic mixing, thereby favoring substantially increased ET than for the understory vegetation in the uncut portion of the stand or in the partially harvested stand. In addition, changes in the amount of understory vegetation may influence the relative losses from transpiration and evaporation from the forest floor or clearcut. The net effect of these differences on total ET of the two stands is not known.

Research is being conducted on each component of ET, with the goal of developing and testing techniques for estimating the ET components independently. If successful, this research will provide methods for assessing how total ET may be manipulated through stand treatment. Furthermore, this research may bring us closer to the ability to estimate each term of the hydrologic cycle independently without obtaining any component by difference ("closure"), and it may facilitate relating summer hydrologic processes to processes important in tree ecophysiology and in nutrient cycling.

Winter ET

Winter water vapor losses do not appear to be as complex as summer ET losses, although they are not well understood. Winter losses in subalpine forests are primarily through sublimation of intercepted snow (or evaporation of snow meltwater on branches if air temperatures are warm enough) and sublimation of the snowpack. Transpiration of trees is negligible during winter months because of stomatal inactivity and freezing conditions in the soil-plant system.

Data summarized by Meiman (this volume) indicate that snowpack water equivalent can be linearly increased up to 30% or more as basal area is reduced, and a significant portion of the annual increase in water yield associated with timber harvest is related to the associated reduction in interception loss. Consequently, LAI and the spatial distribution of foliage in trees and stands influence winter interception and evaporation in much the same way they affect summer interception and ET. Effects on snowpack evaporation are not well understood, but it has been shown that energy input through air movement and, to a lesser degree, solar radiation influence winter evaporative rates in much the same way they are presumed to affect understory ET during the summer.

SUMMARY COMMENT

All aspects of forest management, for whatever intended purpose, and all aspects of forest ecosystem behavior center on trees as the main biological unit and on stands as the organizational structure within which they function. Complex and dynamic silvicultural and hydrologic processes are thereby linked at the stand and tree level. An understanding of these processes may be helpful in forest management and in assessment of subalpine forest ecosystem function. Continued research on tree and stand behavior will increase our understanding of all the biological and physical implications of stand management and environmental change.

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Influence of Forests on Snowpack Accumulation

James R. Meiman[1]

Abstract--There is ample evidence that both small patch cuts and thinning increase snow accumulation in the treated area. These effects extend well beyond the approximately 50 years of record at the Fraser Experimental Forest. The processes responsible are not yet precisely defined, but reduced snow interception losses appear to be a major factor. There is no evidence from recent studies at Fraser of significant redistribution from forests to openings during between storm intervals.

In the subalpine forests snow is the major source of water supply and an important ecological factor. Thus a better understanding of the processes that influence the accumulation, redistribution and ablation of the snow cover is essential for effective management of subalpine forests. This paper focuses on the influence of forests on snowpack accumulation. Other factors that influence snowpack accumulation include climate, topography and nonforest vegetation. Although a brief review of literature on related studies is given, the emphasis is on the work at the Fraser Experimental Forest where the author has worked in association with the US Forest Service over the past 20 years.

Studies Related to Fraser Experimental Forest

Among the earliest recorded observations in the United States on the influence of forests on snow accumulation were those made by Carpenter (1901), Church (1912), Jaenicke and Foerster (1915) and Betts (1916). The most graphic description was given by Church who described the ideal forest for snow accumulation as resembling a giant honeycomb, the glades of the forest representing the cells of the comb.

Miller (1964 and 1966) presented two comprehensive reviews of interception processes and transport of intercepted snow during snowstorms. In these reviews Miller discussed the factors influencing the adhesion of snow on foliage temperature, wind and characteristics of the obstacles; and the factors influencing cohesion of snow atmospheric and crown conditions. Processes involved in transport of intercepted snow from tress included snow sliding from branches, stem flow and dripping of melt water, vapor transport from melt water and snow and removal of snow by wind. These two publications provide an excellent set of references on snow interception processes.

Meiman (1970) reviewed approximately 70 North American studies on snow accumulation in relation to elevation, aspect and forest canopy with emphasis on the subalpine and montane zones. This review illustrated that although elevation has a greater effect on snow accumulation on a large scale, forest canopy can have a dramatic effect over very small distances. Among the studies reviewed that attempted to give a quantitative relationship between snowpack water equivalent and canopy density, Packer (1962) reported a 0.42 inch increase per 10 percent decrease in canopy, Lull and Rushmore (1960) indicated a value of 0.33 inches, and Kittredge gave values ranging from 0.50 inches to 2.2 inches.

The study by Gary (1974) of snow accumulation as influenced by a small clearing in a lodgepole pine forest is relevant to the Fraser Experimental Forest work because it was located in an area with similar climate and stand conditions. He found an increase of approximately 24 percent in peak snow water equivalent in a one tree height wide (1H) clearing. Further, he found the excess water equivalent in the opening was nearly equal to the deficit in the leeward forest zone. The author commented that he could only conjecture as to the processes responsible for the greater accumulation in the clearing. Among the processes discussed were backeddies of the airstream during storms and/or redistribution from the leeward forest border during or following storms. An alternate hypothesis was that the greater snow in the clearing was offset partly by greater loss by vaporization in the sun exposed lee forest. The author did not discuss reduced interception loss as a possible cause of the increase.

In a follow up study Gary (1980) increased the width of the 1H clearcut to 3H and 5H in consecutive cuttings. The width

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extension was done on the lee side of the original cut. Data for 10 winters indicated an average net loss of 6.5 percent for all widths when the volume of snow in the opening plus that in the lee forest was compared with the upwind forest even though there was 20 to 48 percent greater snow accumulation in the openings. Sublimation and wind transport outside the plot (i.e. into the lee forest beyond the measured area) were thought to account for the loss. For two of the ten years, barriers were constructed along the lee side of the 3H opening. For the 1974 snow year a belt of small (5-1/4-foot) lodgepole trees was erected along the lee border of the cut area. For the 1978 winter a 12-1/2-foot wood snow fence (40 to 50 percent density) was used. Placement of the barriers did not change the expected pattern of snow accumulation inside the clearing but snow catch along the lee side of the clearing and lee forest border was greatly altered. The fence was more effective than the trees and resulted in a 13 percent net snow increase on the study plot (opening plus lee forest). The barriers provided evidence that considerable amounts of snow are transported away from the lee forest border by wind action.

A set of studies in Canada (Golding and Swanson, 1986) have particular relevance to Fraser studies. At the James River study area, 60 miles northwest of Calgary, Alberta, the authors reported a spatially preferential loss from the snowpack in different sectors within forest clearings. The implication from this study is that differential ablation during the accumulation period can be an important factor in evaluating differences in snowpack accumulation in forest openings. At the James River study site snow water equivalent in 1/4H to 6H circular clearings ranged from 13 to 45 percent greater than in the forest and was reported to be "probably" a result of a combination of interception and redistribution.

At the Marmot Creek experimental watershed 24 miles SE of Banff, Alberta, clearings on two subbasin clearings were studied Twin and Cabin. On the Twin subbasin, clearings of 3/4 to 1-1/4H had 28 percent greater snow water equivalent than the intervening forest which the authors reported "seemed" to be the result of redistribution because the increase in the clearings just balances the decrease in the forest (based on an calibration with separate control area). On the Cabin subbasin the 20 to 32 acre blocks averaged 20 percent greater snow water equivalent than the forest and there was no evidence of redistribution of snow. The authors suggest that the increase is the result of elimination of interception.

These studies illustrate the complexity and frustration of trying to separate the interception redistribution ablation effects on snow accumulation and, as the authors indicate, ". . . the data do not provide definitive answers concerning the source of increased snow water equivalent in forest clearings."

Gary and Watkins (1985) reported on the effects of thinning a lodgepole pine stand in Wyoming at an elevation of 9000 feet. The thinned area had a lodgepole stand of 10,000 stems/acre before thinning and was thinned to a density of about 850 trees/acre with a basal area of 70 ft2/acre. The remaining trees had an average diameter of 4 inches and an average height of 30 feet. Comparison with a control area before and after thinning indicated a peak snow water equivalent increase of 2 inches or approximately 30 percent.

Fraser Studies

Wilm and Dunford (1948) reported the first comprehensive snow accumulation studies at Fraser. Twenty harvest cutting plots were established in 1938. The five acre plots were in mature lodgepole pine (Pinus contorta) intermixed with Engelmann spruce (Picea engelmannii) and alpine fir (Abies lasiocarpa). The stand contained 300 to 400 trees per acre larger than 3-1/2 inches d.b.h. with a height range for most of these trees between 35 and 85 feet. The merchantable timber volume (trees larger than 9-1/2 inches d.b.h.) averaged 12,000 board feet per acre. These stands were at an elevation of 9150 to 9700 feet. The experiment was designed to place four treated and one control plot in each of four randomized blocks. In 1940 all trees larger than 9-1/2 inches d.b.h. were removed from one plot in each block; three other plots were cut to a residual stand of 2000, 4000 and 6000 board feet of merchantable volume per acre.

In order to determine the effects of timber cutting on snow storage, 25 sampling points were established in each plot. Snow water equivalent was measured with a Utah snow sampler and weighed with a balance to 0.1 ounce between March 15 and April 1. These measurements were taken in 1938 and 1939 before cutting and in 1941 to 1943 after cutting in 1940.

The after harvest values as adjusted by Wilm and Dunford are presented in table 1. These values were calculated by covariance analysis used to adjust for aspect and yearly snowfall differences. Thus the heaviest cutting resulted in a net gain of 1.99 inches or 26 percent over the uncut plots. Snow accumulation increased in relation to intensity of cut. In presenting these results on snow accumulation, the investigators wrote as follows:

> The smallest quantities were observed under clumps of trees, and the largest quantities in the largest available canopy openings, about 60 feet in diameter. These observations provide a graphic clue to the probable effect of timber cutting on snow storage, because such treatments would increase the number and size of openings in the forest, and hence it should increase the average amount of stored snow.

Another important finding came from these early studies. On one half of each cut plot a minor timber stand improvement

Table 1.--Initial snow storage as a result of timber cutting (Wilm and Dunford 1948).

Treatment	Inches of water
11,900 f.b.m. uncut	7.60
6,000 f.b.m. residual stand	8.41
4,000 f.b.m. residual stand	8.61
2,000 f.b.m. residual stand	9.09
0 f.b.m. residual stand	9.59

was made by removing undesirable trees within the diameter range from 3.6 through 9.5 inches. The number of trees removed averaged 56 per acre. This treatment resulted in an average increase of 0.46 inches in snow accumulation or about a 5 percent gain.

In addition to comparing the initial snow storage (i.e. snowpack accumulation as of March 15 April 1), a comparison was made of net spring precipitation (mostly snow) during the period from March 15 April 1 to June 30 by using nonrecording rain gages on each of the plots for the years 1941 to 1943. These results from Wilm and Dunford are presented in table 2. Wilm and Dunford made several salient observations on the spring period results pointing out that about four fifths as much water was supplied by this source as by stored winter snow, and that the percentage increases resulting from heavy cutting were very similar to those found for winter snow storage.

Although Wilm and Dunford did not specifically mention the cause of the increased snow accumulation in their original work, later interpretation by Goodell and Wilm (1955) attributed it to the elimination of evaporation losses from snow intercepted on tree crowns.

Hoover and Leaf (1966) summarized much of their observations on snow interception at Fraser. Based on photographic records during the 1963 and 1964 snow season and long term measurements on Fool Creek, they inferred that snow redistribution could be a major factor causing differential snow deposition. This inference was based on their observations that snow remained on trees a relatively short time at their observation site near the Fraser Experimental Station headquarters, that the analysis at that time indicated no overall increased snow accumulation on the Fool Creek Watershed as a result of cutting, and that, despite considerable regrowth of young trees on the clear cut and heavily thinned plots of Wilm and Dunford, the ratio of treated to uncut plots had changed little if any. In concluding, the authors emphasized the extremely complex series of processes related to the accumulation and disposition of intercepted snow and called for additional studies on the aerodynamic processes involving transport of snow through and from the forest canopy.

Clearcut Studies

The Fool Creek watershed has been an important source of information on snow accumulation. This data was summarized most recently by Troendle and King (1985). The Fool Creek gage was constructed in 1941; the East St Louis gage in 1943. These watersheds were calibrated from 1943 to 1952. Roads were constructed on Fool Creek in 1952 and timber was harvested in 1954 1956. Forty percent of the 714 acre watershed was cut in alternating strips with uncut forest of 1 to 6 tree heights wide (66 to 396 feet). Snow water equivalent was sampled at approximately 100 points on each watershed on or about April 1 from 1943 to 1954 prior to cutting on Fool Creek. Postharvest measurements at the same points were reported for 1959 and from 1967 to 1984. Intensive measurements were made to compare the cut and uncut strips in 1964 and 1979.

The observed peak snow water equivalents on Fool Creek and East St Louis Creek along with the estimated increase on Fool Creek are presented in table 3. This analysis indicates a 1.0 inch (9 percent) watershed wide increase in snowpack water equivalent as a result of the timber harvest on Fool Creek. This is the first reported analysis to indicate an increase in snowpack on the overall watershed. If all of this 1.0 inch increase occurred on the 40 percent cut area, then the average increase on the cut area would be 2.7 inches. This appears well within the 3.4 inches (23 percent) increase reported by Leaf (1975) in comparing the cut and uncut strips on Fool Creek. An additional set of measurements were made on selected strips to check the cut versus uncut snow in 1979. The average increase on the cut strips was 3.8 inches (28 percent).

The exact processes responsible for the increased snow in cut areas are still not clear. Recent work at the Fraser Experimental Forest by Troendle and Meiman (1984) using snowboards in small openings (1.5H) and in the adjacent forests confirmed the increases in the openings, but did not support the concept that snow was redistributed from the forest into the openings during the intervals between storms. Furthermore, the percentage increase indicated by snow-

Table 2.--Net precipitation during spring snowmelt period as a result of cutting (Wilm and Dunford 1948).

Treatment	Inches of water
11,900 f.b.m. uncut	5.73
6,000 f.b.m. residual stand	6.60
4,000 f.b.m. residual stand	7.01
2,000 f.b.m. residual stand	6.94
0 f.b.m. residual stand	7.56

Table 3.--Comparison of snowpack peak water equivalents (inches of water) on Fool Creek and East St Louis Creek Watersheds (Troendle and King 1985).

Year	East St. Louis	Fool Creek	Est. Incr. Fool Creek[1]
1959	12.1	15.8	1.6
1967	9.6	12.2	0.8
1968	11.3	12.7	--0.6
1969	10.0	12.0	0.2
1970	8.0	19.0	0.4
1971	16.3	20.1	1.1
1972	10.6	15.3	2.8
1973	7.8	11.4	2.1
1974	12.7	15.6	0.7
1975	9.8	12.5	0.9
1976	9.2	12.9	0.9
1977	5.8	8.1	1.1
1978	12.8	15.9	0.9
1979	11.4	15.6	2.2
1980	13.9	18.4	2.1
1981	5.4	7.8	1.3
1982	...	...	...
1983	12.6	15.6	0.8
1984	15.1	17.2	--0.5
Average			1.0

[1]Estimated as PWE = PWE (Fool Creek) (0.37 + 1.146PWE East St Louis), $R2 = 0.93$, standard error = 1.0 inches; where PWE = peak water equivalent.

board measurements were larger than those found by snowpack water equivalent comparisons, thus indicating a relatively greater vapor loss from the snowpack in the openings. The data for the 18 events measured in January through March, 1984 are presented in table 4. The average increase in the opening compared to the windward forest was 31 percent. In only one of the plots was there a significant difference in the downwind plot. Very little redistribution occurred between the 18 snow events. The accumulated amount of snow measured in the openings averaged 133 inches, approximately 0.8 inches or less than 1 percent was measured in the between snowfall intervals.

In order to measure more carefully the water balance effects of patch clearcutting, a plot study was established on a 35 percent north facing slope at the Fraser Experimental Forest at an elevation of 9200 feet. The site was a uniform forest of Engelmann spruce, subalpine fir and lodgepole pine with an average canopy height of 64 feet. In 1980 the site was divided into three equal plots 260 feet wide and 400 feet long. In the summer of 1982 the center plot was clearcut after two years of calibration measurements of snow water equivalent and soil water content. Comparison of peak snow water equivalent for five years are presented in table 5. The increased accumulation averaged 5.8 inches of water or 45 percent more than in the upwind plot (probability < 0.001). Furthermore, there was no significant difference in the downwind forest plot.

Twelve snowboards were placed on each plot and read at 20 different times during the period between January 2, 1985 and April 4, 1985. The boards were read after each storm and during nonstorm periods to determine when storm redistribution occurred. The average accumulation on all boards in the open was 104 inches of snow (depth, not water) compared to 68 inches in the forest giving a 65 percent increase. Virtually all of the increased accumulation occurred during, not after snowfall events. There was no difference between upwind and downwind forest plots. These results confirmed the earlier results (Troendle and Meiman, 1984) obtained on three openings 1.5H in diameter.

The most recently completed study at Fraser of snow accumulation is that of Wheeler (1987). He used the same plots as were used by Troendle and Meiman (1986), but greatly increased the number of events sampled and the sampling intensity. Each snowboard sample was weighed to determine actual water equivalent on the snowboard. In addition to the snowboard measurements, a recording anemometer was installed on a tower at 70 feet above the ground in the center of the clearcut plot. During the period from January to April, 1986, 22 snowfall events and 21 inter storm intervals were observed. Redistribution from the forest to the clearing was observed only one time and accounted for only one percent of the difference in accumulation in the clearing.

Snow accumulation in the upwind and downwind forest was compared for seven storms. None of the storms showed a significant decrease in the mean snow water equivalent in the downwind forest. A comparison of the clearing with the upwind forest indicated a 31 percent greater accumulation in the clearing for the 21 storms. An analysis of average wind speed during the storm as related to the percentage increase in the clearing resulted in a strong negative correlation $r = 0.74$ ($p = 0.002$). The inference drawn from the lack of downwind effect and the negative correlation of snow increase in the opening with increase in windspeed was that snow interception was the dominant process influencing increased snow accumulation in the clearing.

The recommendations from earlier studies that a watershed be treated with 5H circular openings was implemented in the North Fork of Deadhorse Creek in 1977. Timber was removed on 36 percent of the area by commercially clearcutting 12 small units approximately 5H (400 feet) in diameter. All slash was lopped to a 4 inches top and scattered. Comparative snow course observations between Deadhorse and East St Louis Creek began in 1967. Transects consisting of a total of 118 sampling points cross all major slopes, aspects and elevations on Deadhorse. Snow samples using a federal snow sampler are taken about April 1 each year.

Covariance analysis of the pre and post treatment data indicated no overall change in snowpack water equivalent on Deadhorse North Fork Watershed following timber cutting (Troendle and King, 1987). The authors attributed this lack of difference in snow accumulation to the offsetting influence of greater snow ablation in the openings on this south facing watershed. Intensive sampling of several of the openings and the surrounding forest in 1981 indicated an 18 percent greater accumulation in the openings. Because of the potential confounding of differential ablation with accumulation processes,

Table 4.--Comparison of snow accumulation (inches) in the forest and open averaged for 18 snow events and comparison of peak snowpack water equivalent (percent) on April 1.

Unit	Windward forest	Open	Leeward forest	% increase in open	% increase in snow water in open, April 1.[1]
1	5.7	7.4*	4.8*	30.3	26
2	4.5	5.9*	4.1	31.6	16
3	4.5	5.9*	4.3	31.6	16

*Significantly different from windward forest at P = 0.05.

[1]Federal snow sampler measurements.

Table 5.--Peak snow water equivalent (inches) as a result of timber cutting (Troendle and Meiman 1986).

Year	Upwind plot	Cut plot	Downwind plot
1981	6.1	6.2	6.1
1982	12.2	12.5	12.5
		------- Center plot cut -------	
1983	11.9	17.2*	12.3
1984	14.8	21.3*	14.4
1985	11.8	17.5*	Missing

*Significantly different from upwind plot ($p < 0.001$).

it is not possible to separate interception and differential deposition processes in this data.

One final study deserves mention in relation to clearcutting. The optimum size of clearcuts generally has been given as approximately 5H (Troendle, 1983) with the assumption that larger openings are subject to wind scour. A study was initiated in 1981 to see if larger openings would hold more snow than the adjacent forest if sufficient roughness were maintained in the form of slash and non commercial trees (Troendle and Meiman, 1984).

In 1981 an 20 acre area surrounding one of the original 8 acre clearcut plots studied by Wilm and Dunford was clearcut along with the original 8 acre area. All merchantable trees were removed, the slash lopped and scattered and most of the larger trees felled. About 4 to 6 cavity trees per acre as well as the non commercial stems less than 6 inches d.b.h. were left standing.

In the summer of 1983, all remaining trees on the site were felled. A layer of slash up to 24 inches high remains. Peak snowpack water equivalent measured around April 1 in 1982 and 1983 after the original 8 acre plot (5 acre cut + 3 acre boundary) was recut produced no scour in the original 8 acre area as a result of the now 28 acre opening. This indicated there was still enough roughness in the slash and remaining trees to protect the area from scour. After the removal of all remaining trees in 1983, the accumulation patterns were as presented in figure 1. These results suggest that the slash is still an effective snow trap in the large opening, but once the snowpack reaches the level of the slash then effectiveness decreases.

Thinning Studies

Beginning with the work of Wilm and Dunford a number of studies have been conducted at Fraser over the years on the effects of partial cutting on snow accumulation. These studies have been somewhat overshadowed by the Fool Creek cutting and the emphasis on small clearcuts as the preferred water yield management practice.

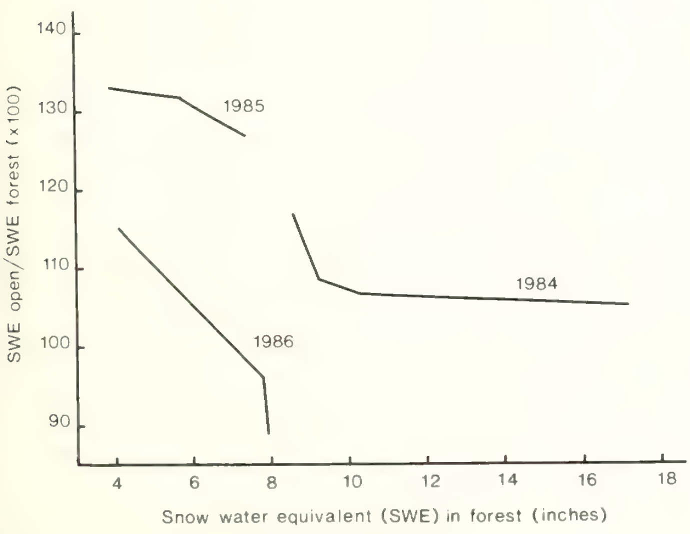

Figure 1.--Comparison of snow water equivalent in open to forest as season progresses.

Hoover and Leaf (1966) presented data on follow up measurements on the original Wilm and Dunford plots. Their measurements for 1956 and 1964 have been added to the original data and are presented together as table 6. In presenting the remeasured plot data, Hoover and Leaf emphasized that the relative snow storage amounts had changed little if any between 1941 and 1964 in spite of the considerable regrowth of young trees and increased canopy density on the more heavily cut plots. They attributed the effect on the 0 and 2,000 f.b.m. plots to the trapping of snow from surrounding old growth trees, but pointed out that a longer regrowth period was needed for more conclusive results. It is of interest to note that the 6,000 and 4,000 f.b.m. thinning effects persist as well as those on the more heavily cut plots.

Troendle and Meiman (1984) analyzed records for one of the original Wilm and Dunford clearcut plots for the period 1941 through 1981. This analysis indicated that the increased snow accumulation in the clearcut area has been diminishing by 0.028 inches per year since 1941. In the 40 year period the recovery was 1.14 inches of the original 2.95 inches difference. Using a linear fit, total recovery would take 103 years. However if the nonlinear growth curve is assumed, total recovery could be expected in a shorter period of time.

Peak snow water equivalent has been measured on four different stand densities in lodgepole pine beginning in 1978. Each thinning level is applied to a 0.5 acre site and replicated five times. These data are presented in table 7 and have been reported in part in Gary and Troendle (1982) and Troendle

Table 6.--Snow storage on lodgepole pine harvest plots.

Merchantable reserve stand per acre (f.b.m.)	Before treatment 1938-9[1]	1941-3[1]	After treatment 1956[2]	1964[2]
	(inches of water)			
11,900, uncut	6.5	7.0	8.4	4.8
6,000	6.8	8.0	----	5.6
4,000	6.9	8.7	10.8	6.3
2,000	7.0	9.7	----	6.8
0	6.8	9.7	11.6	6.7

[1]From Wilm and Dunford 1948, unadjusted data.

[2]From Hoover and Leaf 1966.

Table 7.--Maximum snowpack water equivalent (inches) as related to basal area (ft^2 per acre).

Year	Basal area 140	120	80	40
1978	9.9	9.1	9.6	10.2
1979	8.7	8.9	9.8	10.4
1980	10.5	11.2	11.6	12.1
1981	--	3.3	3.5	3.9
1982	8.3	8.3	8.9	8.9
1983	9.1	9.5	9.5	10.1
1987	6.0	5.8	6.4	6.4

and Meiman (1984). There is a consistent significant difference ($p = 0.05$) between the 40 and 140 levels. Although there is a general trend of increased snow water equivalent with decreased basal area at the intermediate levels, these are not statistically significant.

A much larger scale thinning study was established on Unit 8 of Deadhorse Creek. Unit 8 is a 100 acre north facing slope that was partially cut in 1980 in the first step of a three step shelterwood cut. Approximately 40 percent of the basal area was removed as individually marked trees 7 inches d.b.h. and larger. Peak snowpack water equivalent on Unit 8 was compared to that on the East St Louis Creek control for 14 years prior to thinning and four years after. The r value for the pretreatment correlation was 0.98 with a standard error of 0.2 inches. Peak water equivalent compared to the control increased 1.9 inches or 16 percent over the entire unit (Troendle and King, 1987). The results from this study indicate that the thinning effects found on plot studies also apply to larger thinned areas and, therefore, strongly suggest that the process responsible is interception.

Troendle (1987) in attempting to summarize data on thinning and clear cutting at Fraser and related studies developed the relationship presented in figure 2 illustrating the general relationship between basal area and snow accumulation.

Summary and Management Implications

Fifty years of studies at Fraser have given us a wealth of information on the influence of forests on snow accumulation. There is ample evidence that both clearcutting and thinning produce significant increases in snow accumulation on the

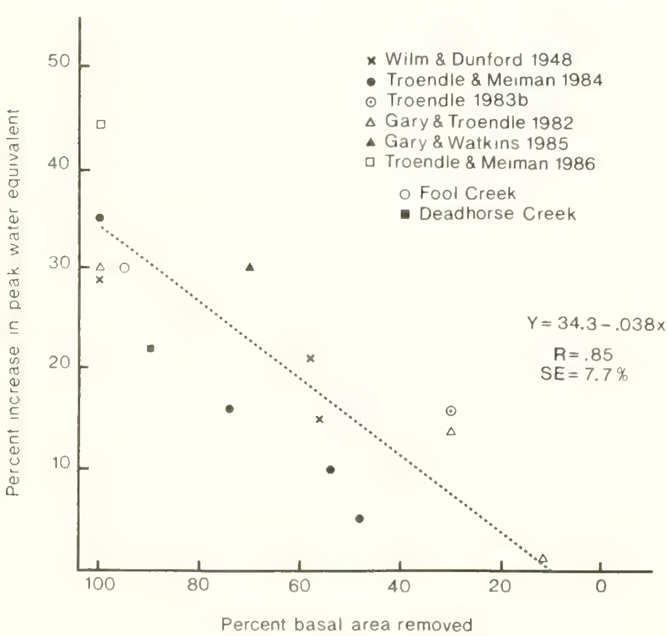

Figure 2.--Summary of cutting experiments at Fraser (Troendle 1987).

treated areas. The increase on Fool Creek in the cut areas appears to be approximately 23 percent and on the North Fork of Deadhorse Creek approximately 18 percent. Considering the entire watershed including cut and uncut areas, there is an overall 9 percent increase on Fool Creek and no increase on North Fork of Deadhorse Creek. These effects of clearcutting small areas appear to be long lived, at least well beyond the almost 50 years of records to date. There is also some evidence that we can achieve snow accumulation increases on cut areas larger than 5H if we pay attention to maintaining sufficient surface roughness through slash disposal and residual trees.

Increases from thinning are somewhat more variable, but information to date indicates increases from 10 to 25 percent for basal area reductions of from 40 to 80 percent respectively.

Demands on forest managers can change over time therefore the best knowledge base for sound management is a thorough understanding of processes responsible for changes brought about by different management practices. The effects from both thinning and clearcutting have been demonstrated on watershed as well as on plot studies. However a thorough understanding of the processes responsible is not yet in hand. The longer data base now available indicates a 9 percent net increase of snow on the overall watershed on Fool Creek thus suggesting interception savings are important. We have not found significant redistribution of snow from forest to openings during the intervals between storms. Still inseparable are the processes of interception and differential deposition during snowfall events. Hopefully the snowfall process studies using snow particle counters now underway at Fraser will help us define better what is happening during snowfall events. We have not found consistent decreases of snow accumulation in forests downwind from openings. In those instances where such decreases have been observed, it is not clear to what extent wind scour has moved snow deeper into the forest. There is also evidence that differential ablation in the open areas and adjacent forest borders is a more important factor in the subalpine than previously thought.

All of the above reinforce the need to continue the process studies together with the larger area watershed measurements. It is this combination of integrated process, plot and watershed studies that has made Fraser such a valuable source of information for land managers through these past 50 years.

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Influence of Forests on the Hydrology of the Subalpine Forest

C. A. Troendle and M. R. Kaufmann[1]

Abstract--Forest vegetation is important in the hydrology of subalpine ecosystems. First, leaf surface area of the canopy presents a massive intercepting surface to both rain and snowfall, much of which subsequently is evaporated back to the atmosphere. The same canopy biomass also transpires significant amounts of water, thereby depleting soil water reserves and increasing storage capacity for subsequent rain or snowmelt that reaches the soil. Reducing the canopy biomass by either partial or clearcutting decreases the interception loss, decreases overstory transpiration, increases understory water use, decreases soil water depletion, and may increase total streamflow, peak flow, and base flow. Increasing stand density has the reverse effect. This paper describes the processes influenced as the forest vegetation is manipulated.

The original classic water balance study in the United States was done at Wagon Wheel Gap on the headwaters of the Rio Grande in southwestern Colorado (Bates and Henry 1928). Streamflow from two watersheds was monitored from 1911 to 1919, and then one watershed was clearcut. In addition to daily streamflow, other factors, such as temperature, humidity, evaporation, and soil moisture, also were monitored. The authors noted that, of the 21 inches of annual precipitation falling on the watershed, approximately 6 inches was returned as streamflow, with almost 15 inches lost to winter and summer evapotranspiration. Following harvest, evapotranspiration was reduced and flow increased an average of about 1 inch. Based on site-specific estimates, the authors partitioned the vapor losses into snow interception, winter and summer ground evaporation, and transpiration. They concluded that (1) much of the opportunity for the observed increases in flow came from net reduction in winter losses, and (2) much of the reduction in overstory transpiration was offset by increased understory transpiration and ground evaporation.

The objective of this paper is to define the water balance of the subalpine forest as we understand it today, as it is reflected in streamflow. The process that we are defining begins with the input of precipitation, considers the opportunities for vaporization, addresses the streamflow generating or transport processes, and identifies the excess or streamflow. In a separate effort, Meiman (1987) addressed the influence of forest on winter snowpack accumulation, and defined the opportunities for influencing that portion of the water balance. In this paper, it will be necessary to use some of the numbers he presented to arrive at annual water balances and estimates of streamflow.

The format for this presentation will be to (1) describe hydrologic response and streamflow generation in the subalpine; (2) describe the annual water balance as indexed by the difference between gross precipitation and measured streamflow, and the integrated changes in that balance that the presence or absence of forest cause at the streamgage; (3) describe the process studies attempting to define the components of the water balance and the role forests play on those processes; and (4) look at the role forests play in mitigating watershed response, with respect to snowmelt peak and individual storm response.

Hydrologic Background

The precipitation regime entering Fraser Experimental Forest is typical of central Rocky Mountain subalpine watersheds. At Fraser, approximately 25 inches of precipitation falls in the headquarters area at 9,000 feet elevation, uniformly distributed through the year. The range is from 15 to over 30 inches, with approximately two-thirds occurring as snowfall. The watersheds yield 45% to 55% of that precipitation as streamflow. About 70% of this water yield comes in April, May, and June as the direct result of snowmelt, 5% or less comes directly from summer rainfall, and 25% from a stable and perennial baseflow. Most of the baseflow is indirectly generated from snow. Garstka (1958) estimated 90% to 95% of the total annual yield of the Fraser streamflow comes from snow.

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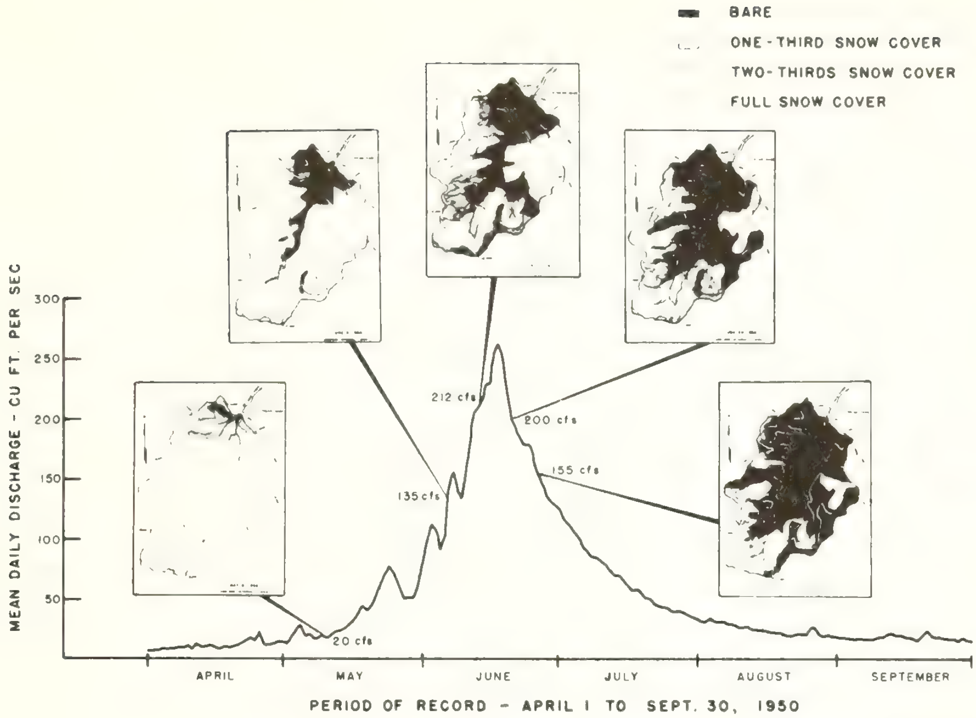

Figure 1.--Snow cover in relation to streamflow (from Garstka et al. 1958).

Figure 1 depicts the relationship between snow cover and the annual hydrograph of the St. Louis Creek watershed at Fraser. It should be noted, however, that the amount of precipitation, the timing of melt, and the generation of runoff are all a function of aspect, elevation, soils, geology, and vegetal cover. Figure 1 represents an integration of everything that is occurring above the streamgage, as does any measured flow data, and there is significant variation within the system.

Fool Creek, on the Fraser Experimental Forest, is a 714-acre watershed, ranging in elevation from 9,500 to 11,500 feet. Currently, two streamgages monitor flow, one from the entire drainage and one at an elevation of 10,500 feet (fig. 2). The upper flume gages the uppermost 162 acres of the drainage consisting of noncommercial forest and krummholtz. Figure 3 presents hydrographs from the entire drainage, that part contributed from the "alpine" area, and that part from the lower forest or harvested area. Flow from the entire drainage was 14.6 inches in 1986: 22.1 inches from the 162-acre alpine area, and 12.4 inches from the 552-acre lower forested portion. The differences in total flow reflect both precipitation and evapotranspiration differences. Most evident, however, is the desynchronization in flow between the lower (9,500 to 10,500 feet) and upper (10,500 to 11,500 feet) portions of the watershed. Both portions contributed more or less equally to peak discharge rate, but the flow volume around the peak was controlled by the larger lower portion (552 acres). A secondary peak, from the alpine area, came 10 days later, and influenced the total watershed flow.

It appears as though both portions contribute equally to baseflow. However, a large storm (1.8 inches of accumulated precipitation) in late July caused a response on the lower portion of the watershed containing the majority of seep areas and live channel, but not from the upper drainage. Storm response for the watershed was only 3% or 4% of the precipitation. For the most part, the upper watershed-lower watershed comparison demonstrates the temporally differential contribution from the high and low elevations that occur on subalpine watersheds.

Since we do not have adequate precipitation data from the alpine area, we cannot estimate the water balance for that drainage. However, flow from the lower portion is less than the average for the entire watershed; therefore, we have been underestimating ET (as P - RO) on that forested portion. The lower, fully forested (although harvested) portion of Fool Creek appears to have a water balance more similar to that for the North Fork of Deadhorse Creek, another unit with no noncommercial alpine area. Figure 4 depicts the unit area contribution from both portions of the watershed, and the alpine area is the far greater contributor.

Effect of Timber Harvest on Water Yield

Numerous paired watershed experiments have been conducted to determine the effect of forest manipulation on the water balance and water yield. Regional summaries have been presented by Douglass (1983), Harr (1983), Hibbert (1983), Kattelmann et al. (1983), and Troendle (1983), while Bosch and Hewlett (1982) summarized the almost 100 experiments world wide. For this paper, we are primarily concerned with those experiments conducted in the subalpine environment.

Fool Creek

Although the Wagon Wheel Gap experiment (mentioned earlier) was the first of its kind in the United States, the Fool Creek watershed study at Fraser is considered the classic because of its long-term record. Streamflow from the 714-acre Fool Creek and its 1,984-acre control, East St. Louis Creek, was gaged for 11 years prior to harvest in 1954-56. Forty percent of the watershed (50% of merchantable forest) was clearcut in alternating cut and leave strips that varied from 1 to 6 tree heights (H) in width and 500 to 600 feet long. Snow courses also were located on each watershed and monitored from 1943 to 1954, in 1956, and from 1966 to present. Troendle

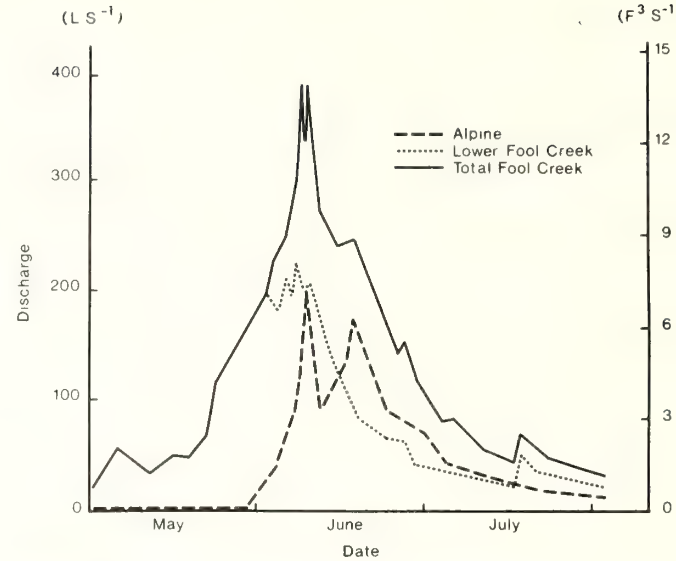

Figure 3.--Daily discharge from the Fool Creek watershed and the contribution made by each component.

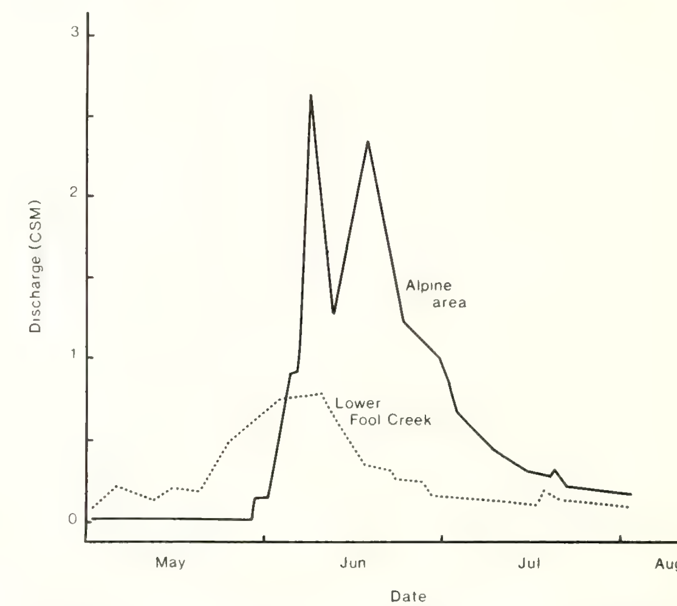

Figure 4.--Unit area discharge from the 162-acre alpine area and the 552-acre lower portion of Fool Creek.

Figure 2.--Fool Creek watershed showing location of streamflow-generating springs and seeps, as well as the location of the two streamgages.

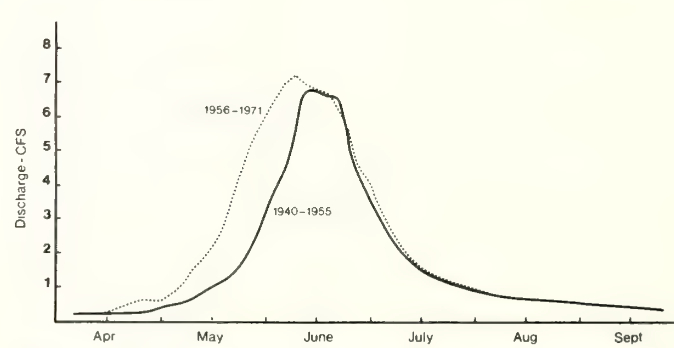

Figure 5.--Average hydrographs from Fool Creek for before (1940-1955) and after (1956-1971) harvest.

and King (1985) recently summarized the effects of that treatment. Flow increased an average of 3.2 inches for the first 28 years after treatment. The first year average increase (increase that would be expected to occur under average climatic conditions) was 4 inches, actual increases were precipitation dependent, and the largest increases (up to 6.4 inches) occurred in the wettest years (table 1).

Two significant observations were made in the recent analysis. First, peak snowpack water equivalent actually increased over the entire watershed by 9%, presumably as a result of reduced interception. Second, for the first time, precipitation records were adequate to allow interrogation of the relationship between various precipitation parameters and flow or change in flow (Troendle and King 1985). The fitted equation was

$$\Delta Q = 0.27 + 0.067\ PWE + 0.11\ SPRPC - 0.04\ t$$

where

ΔQ = estimated increase in flow (inches),
PWE = peak water equivalent on April 1 (inches),
SPRPC = melt period (April 1--July 1) precipitation,
t = time in years since harvest,
Adjusted R^2 = 0.62, and
Standard Error = 0.72 inches.

Table 1.--April to September streamflow from East St. Louis Creek and Fool Creek, and an estimate of the increase (in inches) from Fool Creek due to timber harvest (Troendle and King 1985).

Year	Observed runoff East St. Louis Creek	Observed runoff Fool Creek	Estimated increase Fool Creek[1]
1956	15.6	13.9	3.7
1957	21.4	20.8	6.4
1958	13.1	12.0	3.5
1959	11.9	11.9	4.3
1960	13.9	13.7	4.7
1961	10.1	9.6	3.3
1962	18.7	17.3	4.8
1963	5.2	4.3	1.6
1964	10.1	9.0	2.7
1965	17.5	15.6	3.9
1966	7.8	6.8	2.2
1967	12.6	11.0	3.0
1968	11.7	9.1	1.6
1969	14.6	12.1	2.6
1970	18.4	14.8	2.5
1971	17.8	15.8	3.9
1972	12.3	11.7	3.8
1973	15.2	12.2	2.2
1974	16.0	13.8	3.3
1975	12.7	10.4	2.2
1976	9.5	7.7	1.8
1977	8.0	6.2	1.4
1978	14.6	12.9	3.4
1979	12.8	10.6	4.0
1980	13.4	11.7	3.0
1981	8.3	6.7	1.7
1982	15.2	15.4	5.4
1983	22.6	20.3	5.0

[1]Estimated as $\Delta Q = Q_{F.C.} + 0.94 - 0.717 Q_{E.S.L.C.}$ R^2 = 0.84, standard error = 1.1 inches; where ΔQ is the increase in flow on Fool Creek (inches): $Q_{F.C.}$ is the runoff on Fool Creek (inches); and $Q_{E.S.L.C.}$ is the runoff in East St. Louis Creek (inches).

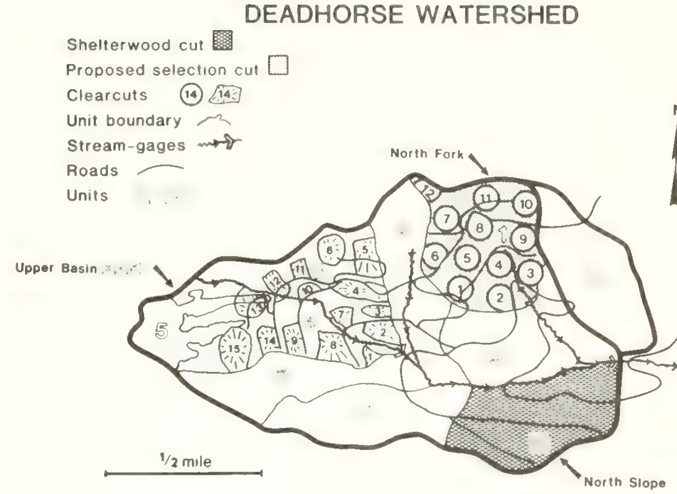

Figure 6.--The Deadhorse complex showing harvesting alternatives applied to the North Fork, North Slope, and Upper Basin.

Summer precipitation (July 1 through October 15) did not significantly correlate with change in flow. It is difficult to interpret the causal relationships between flow, change in flow, and the precipitation parameters in the subalpine environment. Summer precipitation appears to be lost, regardless of presence or absence of vegetation, yet increases in flow are totally precipitation dependent. We obviously are dealing with an arid environment where evaporative losses are significant and influenced by vegetation year round. The average hydrographs for before and after harvest are shown in figure 5. Most of the flow increases came in May. Other monthly flows were virtually unaffected.

Increased flow on Fool Creek has been decreasing at a rate of 0.04 inch per year. The increased peak water equivalent also appears to be decreasing. As the vegetation regrows, the summer and winter ET losses increase, thereby diminishing the increased flow. Analysis of streamflow records indicates the effect of treatment will last 80 years. Separate simulations of stand growth using Rocky Mountain Yield indicate the original leaf area will regrow in 70 to 80 years.

Deadhorse Creek

More recently, the Deadhorse watershed complex was installed and treated. Main Deadhorse Creek (fig. 6), a 640-acre watershed on the Fraser Experimental Forest, was first gaged in 1955. In 1970 and 1975, streamgages also were built on the North Fork and Upper Basin subdrainages. The main watershed and two subdrainages are calibrated against East St. Louis Creek, the 1,984-acre control watershed.

The first treatment was imposed on the North Fork subdrainage in 1977 (fig. 6), when 12 small units were commercially clearcut (Troendle and King 1987). The circular openings were 5-H in diameter and occupied about 3 acres each. Approximately 12,000 b.f.a. was removed per acre clearcut, and 36% of the watershed area was harvested (Troendle 1983a).

In 1980 and 1981, unit 8 (fig. 5) was harvested in the first step of a three-step shelterwood cut. Unit 8 is an ungaged, north-facing slope, 100 acres in area, that lies downstream of both the North Fork and Upper Basin subdrainages and is a part of the 348-acre interbasin area above the main streamgage. Approximately 40% of the basal area was removed by individually marked trees 7 inches d.b.h. and larger. The entire 100 acres was harvested uniformly, removing a total of 730 m.b.f. of sawtimber or 7.3 m.b.f.a. Although the percentage of the total stand removed was the same on the North Fork (36%) and North Slope unit 8 (40%), a greater volume of sawlogs was removed from the North Slope (Troendle and King 1987).

During the summers of 1983 and 1984, approximately 30% of the gaged Upper Basin was harvested in irregularly shaped clearcuts, varying in size from 2.5 to 15 acres. The impact of harvest on the hydrology of the upper basin cannot be addressed yet.

The 5-H circular clearcuts imposed on the North Fork were intended to maximize snowpack accumulation in the clearcuts, and to optimize flow increases for the basal area removed. In contrast, it was reasoned that partial cutting would have little effect on streamflow because (1) in a semi-arid environment such as the subalpine (Leaf 1975), the residual stand would have access to and use any transpirational savings during the growing season; and (2) without clearcutting and the attendant aerodynamic changes, there would be no redistribution of snow, no net change in the deposition pattern of the winter snowpack, and, therefore, the presumed efficiency in delivering water to the stream because of snow redistribution would not be attained. The hypothesis in this assumption was that partial cutting (harvesting by individual tree removal or thinning) would be far less efficient in increasing streamflow than would be the removal of the same percentage of the forest in small (5- to 8-H) clearcuts.

Table 2 lists the flow increases from the North Fork since 1978. The average increase has been 2.4 inches; the variation from 0.8 to 4.2 inches can be attributed to annual differences in precipitation. As was done for the Fool Creek watershed, the individual increases in flow (Q) were regressed on (1) winter precipitation (October 15 through March 30), (2) spring or melt period precipitation (April 1 through June 30), and (3) growing season precipitation (July 1 through October 14). Because of the short posttreatment record, a time or recovery variable (t) was not included in the regression. Winter precipitation (peak water equivalent) entered the equation first ($r = 0.74$, $p = 0.03$), spring precipitation second ($p = 0.06$), and growing season precipitation third ($p = 0.11$). The adjusted R^2 for the multiple fit was 0.76; little was contributed once winter and spring precipitation were considered. As a check, total flow from the North Fork was regressed on the same variables, and the same relationship existed for both the pre- and postharvest periods, indicating that timber harvest did not alter the relative significance of the driving precipitation variables. Summer precipitation was relatively nonsignificant before harvest and remained that way after harvest.

Table 2.--Observed flow and estimate of increase due to timber harvest on the North Fork of Deadhorse Creek (Troendle and King 1987).

Year	Observed flow (inches)	Increase in flow[1] (inches)
1978	10.6	3.2
1979	8.3	4.2
1980	9.1	2.6
1981	3.7	1.4
1982	11.2	3.3
1983	14.6	0.8
1984	15.6	1.2
$\bar{x}$	10.4	2.4

[1]Increase is estimated as: $\Delta Q = QDH - (0.81\ QESL - 4.41)$, where: ΔQ = change in flow, North Fork (inches); QDH = observed annual flow, North Fork (inches); QESL = observed annual flow, St. Louis Creek; $r^2 = 0.98$; and std. error of est. = 0.43.

In a somewhat similar analysis, Troendle (1983) found that the annual variability in total flow and the increases in flow from Wagon Wheel Gap also were highly correlated with precipitation. Low years yielded small increases.

The calibration of flow from the interbasin area on Deadhorse Creek, which includes unit 8, on flow from the control, East St. Louis Creek, was good ($r = 0.9$, standard error = 0.6 inch). Covariance analyses of the adjusted group means for the 6 pretreatment and 3 posttreatment years indicated that flow from the entire 348-acre interbasin area may have increased 1 inch ($p = 0.34$) after partial cutting. This represents a unit area increase of about 3.6 inches from the 100-acre area actually harvested. However, the posttreatment years so far have had well above average precipitation, and we expect the observed increases to be lower under drier or average conditions. The hypothesis in establishing the treatment, however, was that partial cutting would have no effect on water yield.

The calibration of main Deadhorse Creek on its East St. Louis Creek control has an R^2 of 0.95 and a standard error of 0.3 inch based on a 21-year calibration. After 4 years of postharvest record on the North Fork, Troendle (1983a) noted that the significant increase in flow detected at the North Fork gage could not be detected downstream at the main gage. Covariance analysis at that time indicated that mean flow from the 640-acre Deadhorse Creek increased an average of 0.7 inch for the period 1978-1981, but it was not significant ($p = 0.37$).

Currently, covariance analysis still indicates the 1978-1983 adjusted mean for the watershed has not increased significantly, although the net effect of both treatments may have increased the flow 0.6 inch ($p = 0.31$). As stated, estimated change in flow at the main streamgage of 0.6 inch is not significant (at $p = 0.05$), but it is very reasonable, considering the measured change on the North Fork represents a mean change of 0.33 inch over the entire Deadhorse watershed, and the partial cut on the North Slope contributed an estimated 0.35 inch. The total (0.33 + 0.35) of 0.68 inch compares well with the measured estimate of 0.6 inch at the main gage.

Sturgis Watershed 3

The effect of partial cutting was more definitively evaluated in the ponderosa pine type in the Black Hills, near Rapid City, S. Dak., at the Sturgis experimental watersheds (Anderson 1980).

Sturgis watershed 3 is a 190-acre experimental watershed that flows to the north from an elevation of 5,700 feet. It has a total relief of 700 feet. The basic hydrology, geology, and geomorphology of watershed 3 and its 90-acre control, watershed 2, were described by Orr (1969) and Yamamoto and Orr (1972).

After a 7-year calibration period, logging began on watershed 3 in late summer 1970 and finished in 1971. The intent was to reduce the basal area on 130 of the 190 acres to a growing stock level (GSL) of 70. Postharvest surveys showed that, although only about one-half of the watershed area was harvested, approximately 25% of the total basal area on the entire watershed was removed.

The average annual increase in flow was 1.9 inches ($p < 0.001$) for the years 1972-79, with a yearly range from 0.6 to 3.8 inches. Forty-two percent of the increase occurred in April, 19% in May, and 25% in June, for a total of 86% in the 3-month runoff period.

As for the Fraser watersheds, annual precipitation for watershed 3 was divided into three seasonal values--winter (November-March), spring (April- June), and summer (July-October)--and this precipitation parameter was correlated with the observed changes in flow (Troendle 1987). During the 7 postharvest years, winter precipitation averaged 7.2 inches, with a standard error of 2.6 inches, spring precipitation averaged 13.7 $\pm$ 6.1 inches, and summer precipitation average 8.1 $\pm$ 2.4 inches. The mean precipitation for the watershed averaged 29.0 $\pm$ 4.6 inches per year.

Both in terms of total annual streamflow and change in flow after harvesting, spring precipitation was the parameter most significantly correlated with response ($p = 0.01$, $r = 0.50$). Winter precipitation, although significant, was only slightly correlated ($r = 0.10$) with both flow parameters. Summer precipitation was negatively correlated with both flow and the increase in flow ($r = -0.42$ and -0.50, respectively). However, because summer precipitation was negatively correlated equally with total annual and with spring precipitation, the postharvest summer precipitation (either expressed as current precipitation or lagged 1 year to represent previous or antecedent precipitation) was not correlated with either total flow or the change in flow.

Effect of Timber Harvest on Peak Discharge and Storm Response

Peak Discharges

Most watershed experiments in the subalpine environment have demonstrated an increase in peak discharge following vegetation removal. Van Haveren (1981), reanalyzing the data from Wagon Wheel Gap, found that peak discharge increased 50% following clearcutting, although the date of peak flow did not change.

On Fool Creek, Troendle and King (1985) found that, during 28 years of postharvest record, peaks increased an average of 23% and that the increased peaks were positively correlated with peak water equivalent in the snowpack. Unlike Wagon Wheel Gap, the timing of the peak was altered on Fool Creek; the faster melt and quicker satisfaction of soil moisture recharge requirements caused the flow to peak an average of 7.5 days earlier. A second significant observation is that the increase in peak flow, like the increase in total flow, is beginning to diminish with time ($p = 0.10$).

Peak discharge from the North Fork of Deadhorse Creek increased about 50% ($P = 0.07$). However, like Wagon Wheel Gap and unlike Fool Creek, the timing of peak did not change following harvest (Troendle and King 1987).

Peak discharge at the main Deadhorse gage would reflect any impact due to the partial cut on the North Slope and the North Fork clearcuts. No change was detected in either the magnitude or the date of occurrence of the peak discharge at the main Deadhorse gage.

In summary, it appears that timber harvest increases peaks on site, but may or may not influence timing. Even when timing is influenced, it is only shifted 1 week. The downstream effect of peak flow increases probably is minimal.

Stormflow

In a plot study on a 35% west-facing slope above a lateral moraine, Troendle (1985, 1987b) monitored the lateral migration of melt water from the snowpack to the soil, and toward the stream channel. In 1978 and 1979, two subsurface flow collection systems were installed on two separate portions of the 25-acre study area. The collection system on plot 1, a slightly divergent slope, was 50 feet wide, while it was 120 feet wide on plot 2, a slightly converging slope. Both slopes were 700 feet long, and both collection systems were 13 feet deep. They intercepted water moving laterally downslope from the surface, the shallow subsurface (upper 3.3 feet of soil), and from the deep subsurface (from 3.3 to 13 feet). In addition to outflow by horizon, the elevation of perched water tables was also continuously monitored, as were winter snowpack accumulation and precipitation.

Figure 7 depicts typical outflow for the two plots prior to harvest. The scenario is that as snow melts, it infiltrates and percolates, primarily vertically, until an impedance slows it down. The saturated conductivity goes from in excess of 8 inches per hour at the 1-foot depth to 0.001 inch per hour at the 7-foot depth. Since snow can melt at rates up to 0.8 inch per day, the permeability rate can become limiting at depths of 5 to 6 feet at this site; a perched water table develops and rises toward the surface as melt continues. With the creation of the perched water table, lateral migration becomes significant and plot outflow, spring flow, or streamflow is generated. Except

for a small portion of surface flow on plot 2, virtually all flow is subsurface (fig. 7). In addition, in excess of 90% of all flow is deep subsurface in nature. Outflow varied with amount of precipitation and usually ended by July or August, with the growing season precipitation retained or used on site.

In late 1984, plot 1 was clearcut to follow the effect of clearcutting on snowpack accumulation, melt, and lateral translation. Figure 8 represents comparative hydrographs from the cut and uncut plots. Following the first full year after harvest, the soils were wetter on the cut plot, as was demonstrated earlier. This required less soil water recharge. Secondly, snowmelt may have occurred earlier and faster, causing flow to begin on the cut plot 1 month earlier than on the forested plot. Peak flow rate was appreciably increased, as was total volume of flow. However, the snowmelt recession side of the hydrograph appeared unchanged, and both plots quit flowing at the same time. Soil moisture content on the forested plot continued to be depleted by evapotranspiration much faster than on the clearcut plot. As a result of several storms, flow initiated a second and then a third time on the clearcut plot. Although at a low rate, the outflow represents a significant increase due to harvest.

This case study provides much insight into processes that generate streamflow, and the effect of management on those processes. And for the first time, it identifies the fact that we may be increasing baseflow from harvested areas.

Effect of Timber Harvest on Water Balance

As noted earlier, Bates and Henry (1928) presented one of the first attempts to quantify components of the water balance based on data from Wagon Wheel Gap. Wilm and Dunford (1948) presented a most thorough water balance study in the lodgepole pine type at Fraser. Five harvest plots representing a control, a clearcut, and three levels of partial cutting (0, 2,000, 4,000, 6,000, 12,000 b.f.a. reserve volume) were replicated in

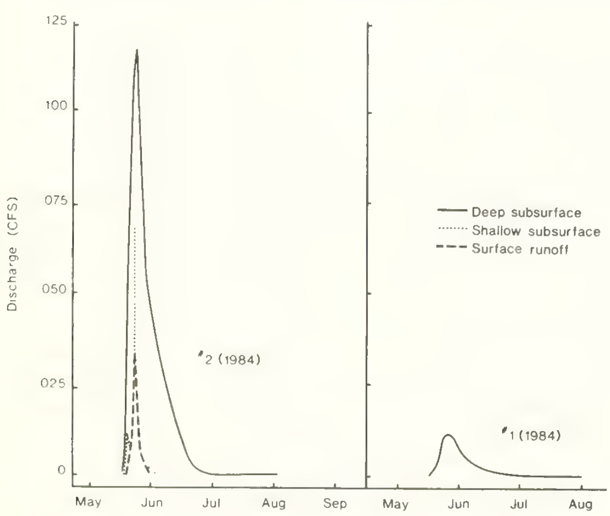

Figure 7.--Outflow hydrographs for plots 1 and 2 for 1984.

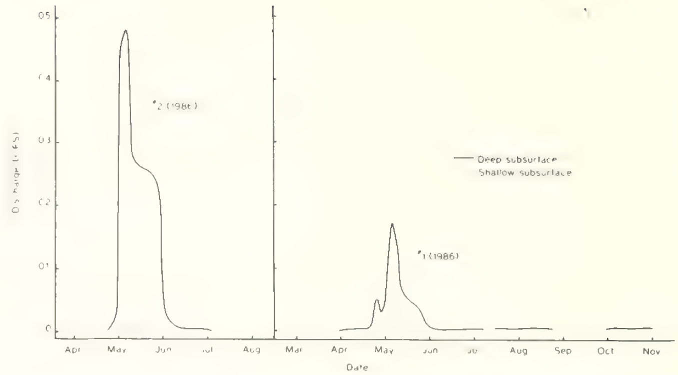

Figure 8.--Outflow hydrographs for plots 1 and 2 for 1986. Plot 1 was clearcut in late 1984.

each of four randomized blocks. They monitored snowpack accumulation, gross precipitation, throughfall precipitation, stemflow, soil moisture (to 18 inches), and evaporative loss. They also estimated evapotranspiration and interception loss.

First, they noted that peak water equivalent in the snowpack increased linearly with reduced stand volume (table 3). Secondly, they noted that overstory interception losses and soil water depletion rates were reduced with reduced stand density. Table 3 notes the changes in the evaporative components they monitored. They concluded that water available for streamflow increased (net ET reduction, table 3) because of both winter and spring interception savings, as well as summer ET reductions. Observed changes in soil water depletion (reflecting a transpiration reduction) were minimal, but they only monitored the upper 18 inches of soil. Subsequent studies indicate significant depletion can occur to 3 feet or more in depth (Troendle 1987a).

In a second water balance study at Fraser, Troendle and Meiman (1986) worked with a north-facing slope. In an unreplicated case study, they divided a 7-acre area, on a uniform 35% north-facing slope, into three contiguous blocks that joined each other on an east-west axis. The stand was a uniform forest of Engelmann spruce, subalpine fir, and lodgepole pine, with an average height of 69 feet.

Ten-neutron probe soil moisture access tubes and 15 snow stake sampling points were systematically located in each block. After 2 years of calibration, the center block was clearcut. Figure 9 depicts the accumulation and ablation pattern on that site, and although significantly more water is stored in the open, it ablates during the same time period, implying a higher melt rate in the open. This process contributes to the greater runoff peaks observed at the watershed level.

Generally, all three blocks were at the same soil moisture recharge level in early June. Soil moisture content on each block then was remeasured two or three times per growing season for 3 years following harvest. Depletion (or recharge) is estimated by looking at differences in moisture content between successive measurements. Evapotranspiration for the measurement interval is estimated as the summation of the change in soil moisture content for the interval plus the

Table 3.--Summary of the effect of different harvesting levels on the water balance of lodgepole pine (Wilm and Dunford 1948).

Lodgepole pine reserve volume	Increase, peak water equivalent[1]	Increase, spring precipitation[2]	Summer interception reduction[3]	Reduced soil water depletion	Net ET reduction[4]
- - b.f.a - -	- - - - - - - - - - - - - - -	- - inches - -	- - - - - - - - - - - - - -		
12,700 (uncut)	0	0	0	0	0
6,000	0.8	0.3	0.6	0	1.1
4,000	1.0	0.5	0.8	0.5	2.0
2,000	1.5	0.2	0.9	0.4	2.1
0 (clearcut)	2.0	0.5	1.2	0.6	3.2

[1]Net change in winter snowpack on April 1.
[2]Estimate of net increase in gross precipitation to the ground during melt period.
[3]Measure of interception savings lost to ET. Not included in ET savings.
[4]Sum of components; represents increase in flow.

precipitation for the interval. The daily ET rate is the total for the interval divided by the length of interval. Table 4 summarizes the ET estimates for the 5 years of study. Soil water depletion was significantly reduced in the clearcut block, as indexed by the reduced ET rate following harvest (Troendle and Meiman 1986).

The ET rates presented in table 5 appear quite reasonable based on watershed balances. The potential impact of the creation of the opening on the water balance of the site can be estimated by summing the ET savings and the changes in snowpack peak water equivalent. Table 5 presents these estimates for the 3 posttreatment years. They represent conservative estimates of potential change, because any errors in the working assumptions would underestimate the impact. However, the 7.8-inch mean increase in water available for streamflow from the cut area shown in table 4 compares well with the observed increases on nearby Deadhorse Creek for the same time period and for the same percentage of area cut (33%). The 7.8-inch increase estimated on site for the clearcut represents a 2.6-inch increase over the entire study area. This potential increase is similar to the observed increase resulting from a similar harvesting practice on the North Fork of Deadhorse Creek (table 2). The comparison does not include any savings that may have occurred in April and May on the study plot, however.

In 1975, another study was started in 60- to 70-year-old lodgepole pine on the Fraser Experimental Forest to test the

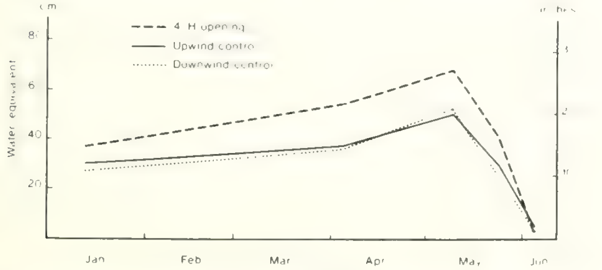

Figure 9.--Snowpack accumulation and ablation on study sites for 1984.

effect of different thinning levels on subsequent growth (Alexander et al. 1985). The study area was divided into five blocks, with one block thinned each year. Within each block, four 0.4-acre plots were thinned from below, each to a different growing stock level (GSLs 40, 80, 100, 120 square feet basal area). The first series of plots in block 1 were thinned in 1976; the last series of plots in block 5 were thinned in 1980. Additional plots in blocks 2, 3, and 4 were added in 1981 and thinned to GSL 160. Adequate stands for GSL 160 were not found in blocks 1 and 5.

Four neutron-probe access tubes were installed to a depth of 5.5 feet in each GSL plot and on the single control plot in block 2. They were installed later on the 160-level plots selected in 1981. Soil moisture was measured at 6-inch-depth intervals periodically during each growing season from 1976 to 1983. The objective of the study was to define the differences in soil water depletion during the growing season as a function of basal area, block or site differences, and years or climatic differences. One obvious problem with the experiment is that in block 1 there was no calibration or pretreatment data and only 7 years of posttreatment record, whereas on block 5 there were 5 years of pretreatment and 2 years of posttreatment data. All years differed climatically.

Linear regression techniques were used to evaluate causal relationships between the rate of change (±) in soil moisture per unit time (dependent variable) and basal area, block or site, midpoint date of the measurement interval, and precipitation during the measurement interval.

Growing-season precipitation is used primarily on site and does not appear to make a detectable contribution to streamflow (Orr 1969, Troendle and King 1985, Troendle and Meiman 1986). Therefore, a second dependent variable, daily evapotranspiration, was calculated. This was estimated as the sum of the soil water depletion between two successive measurements and the precipitation that fell during the interval, divided by the number of days in the measurement interval. At the plot level, this number represents the best estimate of average daily water use (ET) for the measurement interval.

Daily soil water depletion was regressed on daily precipitation, basal area, date (from January 1 until the midpoint of the measurement interval), and block or site. Basal area was the least significant of the independent variables ($P = 0.01$). When the same regression was fitted for each of the individual years, the significance of basal area in the equation depended on whether it was a wet or dry year. In dry years, basal area was not related significantly ($P = 0.50$) to daily soil water depletion.

Figure 10 represents a plotting for all years of record of basal area over soil water depletion. Basal area is significant when regressed on soil water depletion ($p = 0.001$, $r = 0.22$, $SE = 0.02$ inch), but it is apparent that there is much variation in soil water depletion that cannot be accounted for by basal area alone.

Because each year of the study was different climatically, and because not all plots were treated under the same climatic

Table 4.--Summary of evapotranspiration (inches) estimate for measurement intervals (Troendle and Meiman 1986).

Year	Interval dates	Number of days	Plot 1		Plot 2		Plot 3	
			ET	ET/day	ET	ET/day	ET	ET/day
1981	6/9-7/22	43	4.4	0.10	4.3	0.10	4.7	0.11
1982	7/7-9/8	63	6.8	0.11	7.2	0.11	7.4	0.12
				Harvest				
1983	6/28-10/12	105	12.8	0.12	11.1	0.11	12.5	0.12
1984	6/13-9/27	116	13.1	0.11	11.8	0.10	13.7	0.12
1985	6/4-10/9	127	15.2	0.12	12.9	0.10	16.2	0.13
Aver. ET/day	1983-1985			0.12		0.10		0.12

Table 5.--Estimation of potential change in water balance (inches) following clearcutting (Troendle and Meiman 1986).

Year	ET difference	PWE difference	Minimal change
1983	1.6	4.9	6.4
1984	1.6	6.9	8.5
1985	2.8	5.7	8.5
$\bar{x}$	2.0	5.8	7.8

conditions, it is impossible to present an average soil water depletion curve for each basal area.

In the previous example for the partially cut North Slope (unit 8) portion of Deadhorse Creek, basal area was reduced 35% to 40%, or from 180 to 120 square feet per acre. Estimating the seasonal difference in soil water depletion from figure 10, the savings would be 1 inch for the growing season (June through October). As noted earlier, there also was a 1.9-inch increase in peak water equivalent in the spring snowpack. The 1-inch average savings during the 4-month portion of growing season seems reasonable, considering the total increase in flow was estimated to be 3.6 inches at the

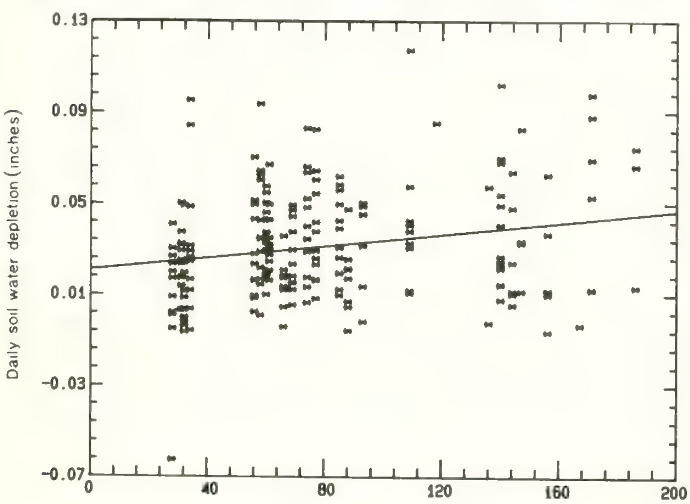

Figure 10.--Relation between daily soil water depletion and basal area.

streamgage. Because any savings in April and May are not included, the combination of the 1.9-inch winter interception savings and 1.0-inch summer depletion savings represents a reasonable portion of the total (2.9 of 3.6 inches). This is a very speculative extrapolation of plot data that is presented only to show that the numbers are reasonable, and that as we add separate components together, the total is reasonable.

As noted previously, total evapotranspiration for each soil moisture interval can be estimated by summing the precipitation that fell during the interval with soil moisture depletion (±). This sum represents the maximum amount of water available for ET, and includes any water lost to deep seepage or streamflow. However, because summer precipitation is not significantly correlated with change in flow, summer precipitation is presumed to be retained on site, thereby reducing soil water recharge requirements (and apparent depletion) or evaporation. Soil water depletion differences between the different basal area levels reflects the net effect of the ET changes. Daily ET rates were not presented in a format similar to the daily soil water depletion rates, because the soil water depletion best expresses the change caused by basal area reduction, especially during rain-free periods. ET averaged 0.14 to 0.17 inch per day.

Soil moisture studies, such as this one and others in the subalpine (Potts 1984, Troendle and Meiman 1986), are not designed to estimate ET, although the estimates of daily use appear to be good. The strength of these studies is in their definition of the soil water deficits in the fall as a function of basal area. These recharge requirement differences reflect the effective net change in the ET processes (pertaining to flow) that result from the change in growing stock levels. These differences are the net effect passed on to the increase in flow when recharge begins. Kaufmann et al. (1987) addressed the components of ET that are being impacted.

Summary

The understanding of the relative role of various evaporative components on the water balance has gone full circle. Very

early observers, such as Church (1912), felt that snowpack accumulation pattern and attendant losses were a dominant controller of runoff and that certain stand configurations were superior to others, with respect to accumulation and subsequent runoff. The results of the Wagon Wheel Gap experiment also pointed out the role of summer evaporative processes on the total water balance. Studies in the 1930s and 1940s confirmed the significance of both winter and summer evaporative processes. Then, in an attempt to improve process definition, there was a conceptual shift in understanding toward one of manipulating ET in the growing season, and controlling or modifying input placement and efficiency of delivery in the winter.

However, more recent research has redefined the significance of both summer and winter evaporative losses. Opportunities for manipulating the water balance through density and tree species control have been identified. Snowpack deposition, both the pattern of accumulation and the amount, can be influenced by any form of stand density control, not just clearcutting.

The questions currently being asked in research have a much higher degree of resolution addressing such topics as the effects of stand structure and species composition, as well as physiographic conditions, on overstory/understory evapotranspiration processes during each season of the year.

Current models that simulate the role of forest on the water balance work reasonably well. The next generation model will do similar things, while integrating precipitation and energy on a more site-specific basis.

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Applying Hydrologic Principles to the Management of Subalpine Forests for Water Supply

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Abstract--WRENSS HP is used to estimate an increase in yield at Fool Creek, Colorado, of 62 mm compared to an actual increase of 67 mm. Similarly, at Cabin Creek, Alberta, WRENSS-HP estimated 7 mm compared to an actual increase of 17 mm. If representative and accurate precipitation data were used, long term actual annual water yields were estimated with no error at either Fool Creek or Cabin Creek. The predicted effectiveness over a 100 year implementation period of 10 ha clear cut blocks as a practice in increasing water yield was virtually identical to that of 1 ha clearcuts if winter wind speeds averaged less that 1 m s^{-1}. At a wind speed of 5 m s^{-1}, the 1 ha clear cut practice produced an increase three times as great as the 10 ha blocks, mainly because of the protection these smaller clearcuts afford accumulated snow from wind and subsequent evaporation.

The management of forests is becoming increasingly complex as various user groups place often conflicting demands upon the same land base. Water users are one such group. Their demands for more water are apparently insatiable.

One of the roles of forest land is watershed. This is a geographical fact that cannot be dismissed. The subalpine forests of the west are among the most important of these watershed as the streams originating on them flow through very arid but valuable agricultural land enroute to the sea.

The virgin forest is not the most efficient watershed in terms of water supply. Many forests can be physically configured, using various clear cut patterns, to make them yield from 20% to 40% more water each year than the uncut condition. Scientists working in the field of forest hydrology have sought to understand the hydrologic system that forests represent and to apply that understanding to the development of management techniques that can be used to provide predictable increases in water yield. My purpose in this paper is to illustrate how the hydrologic procedure presented in the WRENSS handbook (U.S. Forest Service 1980, Troendle and Leaf 1980) can be used to estimate changes in water yield, and the accuracy of the results obtainable with it.

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The Hydrologic Procedure in WRENSS

WRENSS-HP

The WRENSS handbook (U.S. Forest Service 1980) contains a hydrological procedure (Troendle and Leaf 1980) that represents the state of the art for estimating the change in evapotranspiration that will occur when either clear cutting or reforestation occurs on watersheds in the United States and much of Canada (I will call the hydrology portion WRENSS-HP to avoid confusion with the other WRENSS routines.). A change in annual evapotranspiration is a necessary and sufficient condition to affect an eventual (and comparable) change in annual water yield.

Evapotranspiration quantity (ET) is the only portion of a watershed's water balance that we can manage with appropriate forestry practices. WRENSS-HP estimates of evapotranspiration can be used in two ways: (1) directly as estimates of changes in water yield that can be affected by forest cutting; or (2) indirectly within the water balance equation to estimate generated runoff (GRO). The difference in annual evapotranspiration that WRENSS-HP estimates for a forested watershed under uncut and cut conditions is a valid approximation of the change in annual water yield that one can expect from that watershed.

Any land management strategy designed to increase water supply through some form of timber harvest must therefore

reduce evapotranspiration (the amount of water lost to the atmosphere as evaporation from wet surfaces such as the snowpack, leaves, litter and other debris, and from the soil via the stomata on the leaves of trees and other vegetation) if it is to be successful. Contrary to what is often popularly believed, the maximum reduction in evapotranspiration is not generally achieved by removing all of the trees from a watershed. The evaporation process is too complex for such a simple solution. Evapotranspiration is affected by; (1) energy form (e.g. air temperature, solar radiation, wind, etc.), (2) water vapor concentration (e.g. humidity of the air and motion of the air next to any surface with water on it) and (3) water availability (e.g. surfaces, such as leaves or litter, upon which water can accumulate or the proximity of roots to water in the soil). The rearrangement of a forest from one uniformly vegetated to one with discontinuities at tree clearing edges alters all of these. In general, one must reduce the number of trees drawing upon the soil moisture, reduce the total amount of tree canopy, and protect cleared surfaces (and new growth on them) from direct exposure to the sun and wind. The physical configuration of a forest that is to be optimized for supplying water must be carefully crafted and maintained to minimize evapotranspiration.

The WRENSS-HP procedure for estimating evapotranspiration is based on two comprehensive hydrologic models; but WATBAL (Leaf and Brink 1975), is the one most applicable to the snow dominated subalpine forest. The WATBAL model calculates daily ET based on a set of model parameters specific to a particular watershed and daily inputs of precipitation, temperature, etc. The parameters of WATBAL can be adjusted to allow for precipitation (P) and climatic data that may be only indices of true precipitation and climate. The daily values of generated runoff, (GRO) equation [1], that are calculated by WATBAL, can be routed through the storage components of a specific watershed, upon which it has been calibrated, to produce an accurate estimate of each day's streamflow.

$$GRO = P - ET \qquad [1]$$

In contrast, the WRENSS-HP procedure estimates seasonal evapotranspiration as a function of seasonal precipitation within a broad climatic region. It contains no parameters to adjust for indexed precipitation. Nor does it contain watershed descriptors that would allow one to calculate changes in storage (ΔS). Since it contains no provision for estimating storage, nor changes in storage, it cannot be used to estimate the amount of water (routed streamflow) that will be present in a stream channel at any given time. The role of storage is somewhat clearer in the alternate form of the definition for generated runoff, equation [2], where water yield (Y) is streamflow divided by watershed area.

$$GRO = Y \pm \Delta S \qquad [2]$$

With WRENSS-HP, an estimated change in generated runoff for a year or possibly even several years, will generally not be directly verifiable as a change in measured water yield, as the measured yield may be influenced by the unknown magnitude of change in watershed storage. Clearly, generated runoff (eq. [2]) is equal to water yield only when S is zero. In fact, the only circumstances under which GRO, as calculated from WRENSS HP evapotranspiration estimates and equation [1], will equal annual yield or streamflow are: (1) The precipitation data must be accurate for and representative of the watershed under consideration; (2) Changes in storage must equal zero or be averaged over a sufficiently long time period so that their algebraic sum is zero. Although the authors of WRENSS HP suggest that it can be used to estimate both seasonal and annual evapotranspiration, only the annual estimates are verifiable within the water balance equation [1] (within the limits imposed by changes in annual storage). Because of short term storage in the snowpack and soil, the WRENSS HP estimates of seasonal evapotranspiration can only be verified by on-site measurements of seasonal evapotranspiration. Thus one should generally consider the seasonal ET estimates only as intermediate steps in the estimation of annual evapotranspiration.

Availability of WRENSS HP

The complete WRENSS handbook is available from the U. S. Environmental Protection Agency (U.S Forest Service 1980). The nomograms in the hydrology chapter (Troendle and Leaf 1980) can be used to calculate annual evapotranspiration under various forest cutting options. I digitized the nomograms for the snow dominated regions, fitted them to second order equations, and prepared an interactive program for the Hewlett Packard 9825A calculator. These equations have since been used to produce interactive programs for an IBM PC/XT or compatible microcomputers (Bernier 1986). The microcomputer version is the easiest to use, but it may give results slightly different from the nomograms as the snow accumulation and snow evaporation routines are not exactly the same as those published in the EPA handbook.

How to Use WRENSS HP

In order to estimate changes in water yield that can be expected to occur under a forest management scheme, WRENSS-HP is used to calculate the annual evapotranspiration for some baseline condition (usually fully treed), and under the same overall precipitation regime but with some de or re forestation. The difference between the two values is the estimated change in annual yield. In partially clear cut situations, WRENSS-HP apportions differing amounts of precipitation to the cut and treed areas on the following bases:

1. In clearcuts, with maximum windward dimensions less than approximately 15 tree heights, snow accumulates preferentially, presumably at the expense of the surrounding treed area;

2. In clearcuts with windward dimensions greater than 15 tree heights, snow may be removed from a clearing by wind and either sublimate while in transport or be redeposited in the downwind treed areas; this transport can be switched off in our microcomputer versions (Bernier 1986);

3. If the surface of a clear cut is aerodynamically rough, then snow may be retained in place regardless of the windward dimensions.

Some evaporation may occur in situ from the surface of the snow accumulated within a clear cut. In our microcomputer versions of WRENSS-HP (Bernier 1986) evaporation from snow occurs as a function of the wind speed in the clear cut. Our studies have shown that the wind speed 2 m above the surface of clearcuts greater than 20 tree heights across is the same as would occur at either 10 m above the canopy or in completely open situations. In clearcuts smaller than 20 tree heights across, wind speed and evaporation from the snow surface in the clear cut is reduced as a function of clear cut dimensions.

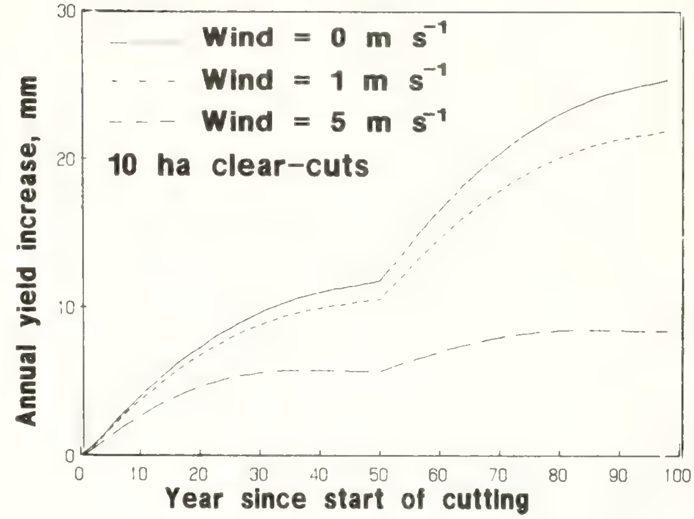
Data Requirements for WRENSS-HP

Land managers have considerable latitude in the use of WRENSS-HP to estimate treatment effects on annual yields. Site specific climatic and streamflow data are not always necessary. A current inventory of timber volume is desirable, but by no means necessary, as estimates by knowledgeable personnel are quite sufficient in most instances.

First Year or Initial Effects

Precipitation by WRENSS-HP season[2].--The distribution of precipitation between seasons is more important when WRENSS-HP is used solely to estimate changes in annual yield than is the absolute amount of precipitation. The amount and representativeness of the precipitation data are of paramount importance in one wishes to estimate actual annual water yield. We have used 5 to 10 year averages or the precipitation from the years with the highest and lowest annual streamflow and noted little effect on estimated change in annual water yield (Swanson and Bernier 1986). These data can be obtained from something as simple as an hydrologic atlas for the area that has isopleths of mean annual precipitation and mean annual water yield. Any reasonably local precipitation station's data can be used to apportion annual precipitation among the percentages applicable to the WRENSS-HP seasons.

[2]The months used in the WRENSS HP procedure's seasons do not correspond to the normal winter, spring, summer and fall periods, although they use the same names!



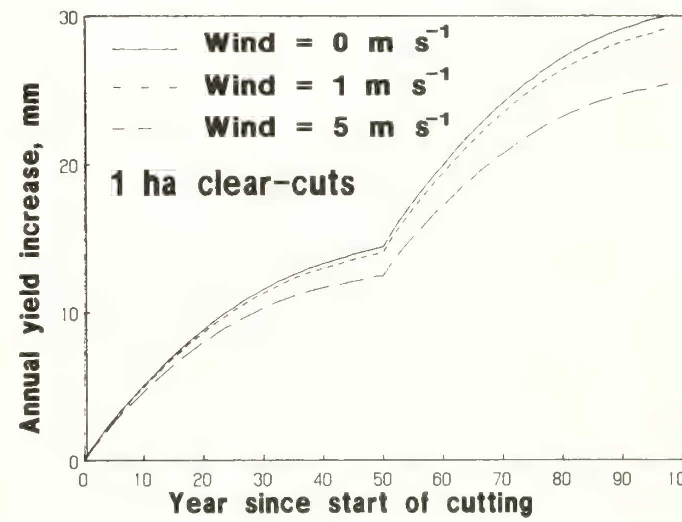


Figure 1.--Progressive effect on annual water yield of annual clear cutting of alternate blocks of mature subalpine spruce-fir forest at 50 year re entry intervals on a watershed throughout a 100-year rotation. With winter wind speeds (October to April) of 1 m s^{-1} or less, the 10-ha clear cut blocks (a) produce only a slightly lower increase in yield when fully implemented than the 1-ha blocks (b). However, the difference in the effectiveness for increasing water yield of the two clear cut sizes becomes much more noticeable when winter wind speeds are much greater than 1 m s^{-1}.

An estimate of average wind speed during the winter and spring.--The windiness of a site has a very marked effect on evaporation of snow (fig 1a). If wind speeds are generally less than 1 m s^{-1}, then wind speed can be ignored (fig 1). If no values for wind speed are available, then one can estimate effects for a range of values and try to verify the actual speed at some later time. If in doubt, it is best to use smaller clearcuts as the surrounding trees protect the snow surface from wind, and ensure higher water yields (fig 1b).

The tree species present, its height and the basal area for a full occupancy (mature?) stand.--This is not critical as estimates of evapotranspiration are made using fractions of this value rather than the absolute quantity.

Basal area that might remain within a clear cut after clearcutting.--In Canada and probably in the United States, some tree species are not considered to have sufficient value to harvest, and are left standing. These generally occupy less than 15% of the total area of any given clear cut, but may need to be taken into account.

The type of treatment, or in the case of clear cutting, the size of clear cut, either in dimensions or as an area.--Our microcomputer version of WRENSS-HP queries one for the clear cut dimension parallel to the prevailing wind direction (Bernier 1986). If this information is not available, then the program calculates it as if it was a square clear cut block of the given area.

The area to be treated and the total area of the watershed.--If the estimates are not for a specific location, then use some convenient unit area.

The general topographic aspect of the area under investigation.--We use east west aspects if no site specific information is available. WRENSS-HP produces considerably different yield estimates for north and south aspects, so if these are known to apply, they should be used.

Effects Throughout a Rotation

Rate of height and basal area regrowth.--We have used a linear function from 0 to maximum height or basal area over the proposed rotation duration to produce the estimates in figure 1. If local data for growth are available, they can be input on a year by year basis to estimate the effect of regrowth on the change in water yield that will occur each year.

The amount of new cutting that will occur and at what frequency.--For example, areas to be harvested in Canada are delineated and divided into a number of areas to be cleared each year. If subsequent cuts in the same watershed are made at five year intervals, than new clearcuts should be introduced into the calculations at five year intervals throughout the rotation.

Mode of implementation.--If a forest is clear cut in an alternate block manner where the treed block between clearcuts are removed at some later time period, the time when these trees are to be removed relative to the state of regrowth in any adjacent clear cut blocks must also be considered.

For example, in Alberta, an area to be managed as one unit within a 100-year rotation is subdivided into 5 compartments. The second and subsequent compartments are not entered until all of the timber from prior numbered compartments has been removed. All of the trees in a compartment are removed during a 20 year period, half in the first 10 years, the uncut intervening blocks in the second 10 years. The second entry to remove the intervening treed blocks creates clearcuts that are surrounded by trees 1 to 2 m tall compared to the original forest at 20 m tall and thus less under the wind speed reduction influence of their surroundings than those clearcuts of the first entry.

Examples Using WRENSS HP

Perhaps the best way to demonstrate the WRENSS HP procedure is to show how it has been applied in various situations. I have chosen as examples the Fool Creek watershed near Fraser, Colo., and the Cabin Creek watershed near Banff, Alberta. Both watersheds are in the subalpine zone. The vegetation on both is primarily spruce fir and lodgepole pine. Both have been partially harvested and the effect of that harvest on streamflow is known. The harvest in small clearcuts at Fool Creek has produced an increase of 89 mm (1956 to 1972, Alexander and Watkins 1977); the commercial sized clearcuts at Cabin Creek 17 mm (1975 to 1984, Swanson et al. 1986).

Precipitation data from two sources are available for both watersheds; the Fool Creek tower and Fraser Experimental Forest headquarters for Fool Creek, the CON 5 station and that from two higher elevation stations weighted in accordance with the Thiessen polygon method, on Cabin Creek. Most of Fool Creek's precipitation occurs between October and May (table 1), most of Cabin Creek's precipitation occurs between February and June (table 2). Their subsurface storage volume is quite different as Fool Creek is on granitic material with a shallow porous mantle (approximately 1 m thick); Cabin Creek on sedimentary material with a porous mantle 6 to 8 m thick.

Change in Estimated Yield as Affected by Source of Precipitation Data

One of the common desires of those using WRENSS-HP is to check its output against measured values. The closeness of any comparison of actual and estimated change in annual water yield or in total annual water yield is influenced by both the representativeness of the precipitation data used and any water stored on a watershed which may appear as streamflow in the next or subsequent years. Differences between WRENSS-HP estimated and measured changes in yield are not particularly affected by the precipitation data used, as long as it is from the same vicinity. For example if the Fraser Experimental Forest headquarters site precipitation data is used to estimate the change in water yield on Fool Creek, the mean value predicted, 58 mm compares favorably the 62 mm (table 3) obtained with the Fool Creek wind tower data. However, the total annual flow predicted with the headquarters data is only 203 mm compared to the 318 mm predicted with the wind tower data (table 3). The differences are more evident on Cabin Creek. When CON 5 precipitation is used in WRENSS HP, the total yield and change in annual yields predicted (table 3) are 195 and 11 mm versus 317 and 7 mm if the Thiessen polygon weighted precipitation data are used (actual annual flow 1975 1984 and calculated increase were 316 and 17 mm, Swanson et al 1986). Although the predicted yield increase is only 40% of actual on Cabin Creek, they are both of the same order of magnitude and neither the predicted

Table 1.--Seasonal[1] precipitation (mm) (Haeffner 1971) and measured annual water yield at Fool Creek, Fraser Experimental Forest, Colorado.

	FEF headquarters			Fool Creek wind tower			Annual	
Year	Winter	Spring	Summer	Winter	Spring	Summer	Yield	Change[2]
1967	200	186	114	263	236	97	280	79
1968	181	131	111	249	176	127	232	48
1969	185	243	136	237	268	132	308	64
1970	264	172	130	350	204	168	376	53
1971	262	169	98	360	226	123	401	91
Mean	218	180	118	292	222	130	319	67

[1]Seasons are: Winter, 1 Oct-28 Feb; Spring, 1 Mar 30-Jun; Summer, 1 Jul-30 Sep.

[2]Change in water yield as estimated by paired basin analysis (Alexander and Watkins 1977).

Table 2.--Seasonal[1] precipitation (mm) and measured annual water yield at Cabin Creek subbasin, Marmot Experimental Watershed, Alberta.

	CON 5 Station			Thiessen Polygon weighted[2]			Annual	
Year	Winter	Spring	Summer	Winter	Spring	Summer	Yield	Change[3]
1977	119	253	221	123	276	259	212	-13
1978	137	235	168	185	336	226	335	-2
1980	218	302	221	146	348	272	377	53
1981	189	362	123	236	421	146	503	103
1983	130	243	165	137	294	185	247	7
77-83[4]	159	279	180	165	335	218	335	30
75-83[4]	175	247	184	-	-	-	316	17

[1]Seasons are: Winter, 1 Oct 28-Feb; Spring, 1 Mar-30 Jun; Summer, 1 Jul-30 Sep.

[2]Data from Davies and Kallenbach (1985).

[3]Change in yield as estimated by paired basin regression (Swanson et al. 1986).

[4]Precipitation data for 1979 and 1982 not included because streamflow is not available for these years.

Table 3.--Estimated and measured values (mm) of long term annual water yield and change in annual water yield with harvest at Fool Creek, Colorado, and Cabin Creek, Alberta. Period of record: Fool Creek/FEF Headquarters, 1965-1971; Cabin Creek, 1975-1983 (1979 and 1982 omitted).

	Seasonal precipitation			Yield		Change in Yield	
Source of data	Winter	Spring	Summer-Fall	Predicted	Actual	Predicted	Actual
FEF HEADQUARTERS	218	180	118	203	319	58	67
FOOL CREEK TOWER	292	222	130	318	319	62	67
CABIN CREEK, CON-5	168	252	187	195	316	11	17
Thiessen POLYGONS	207	314	226	317	316	7	17

nor the actual water yield increases are physically significant to water supply.

The proper choice of precipitation data often is a problem in using WRENSS-HP or any water balance procedure. We rarely have the wealth of data available for both Fool Creek and Cabin Creek. As indicated above, precipitation data from nearby stations is probably suitable for use in WRENSS-HP to estimate changes in annual yield. However, the precipitation data ordinarily available will rarely be representative of the watershed in question, even if it is collected on it. Precipitation stations are often located near a stream gauge which is always at the lowest elevation on a watershed. Since precipitation generally increases with elevation, the precipitation measured at the topographic low will normally be less than that occurring at higher elevations on the watershed. Thus WRENSS-HP estimates of actual annual yields obtained from the water balance equation [1] will generally be less, (often much less as with CON 5 data from Cabin Creek) than measured.

Change in Estimated Yield as Effect by Storage

One should not expect either the change in yield or the total yield for any single year to match that actually measured. Year to year variation in estimated and actual changes in water yield should be expected, especially in watersheds with considerable storage, e.g. Cabin Creek, table 4, all years shown. However, even at Fool Creek, which has almost no storage, the predicted and measured changes in water yield for a given year differ rather widely, e.g. table 4: 53 mm versus 79 mm in 1967; 58 mm versus 48 mm in 1968.

Since changes in storage have such a strong effect on comparisons of measured versus actual data, what period of time should one use to perform such comparisons? I suspect that 5 to 10 years of data should be sufficient.

Discussion

Once one has established a proper forest configuration to minimize evapotranspiration, then the increased volume of water that can be extracted from a watershed is directly proportional to the area of the watershed so treated. Our ability to predict water yields that would occur in the absence of treatment is insufficient to detect increases after treatment that are smaller than about 20%. However, this is a measurement problem, and should not be used as an excuse to not manage for increased yield.

The slow growth of subalpine forests makes water yield increases fairly permanent. The same slow growth may make it almost impossible to restructure a forest for water yield improvement after it has be cleared in some less than optimum manner. For instance, if the best water yielding practice is found to be a 50-50 patchwork of 1-ha clearcuts, than a prior harvest in clearings larger than this will preclude an optimum restructuring for most of the rotation period. However, portions of the forest that have not been harvested can be configured in the optimum arrangement.

Small clearings and windthrow are always a subject of considerable discussion among foresters. Full wind speeds develop 10 to 15 multiples of the height of an object downwind

Table 4.--Effect of year to year carryover storage on estimated and measured values of annual water yield and change in annual water yield with harvest at Fool Creek, Colorado, and Cabin Creek, Alberta.

	WRENSS-HP estimates			Measured			
Year	Wind (m/s)	Uncut (mm)	Cut (mm)	Change[1] (mm)	Yield (mm)	Change[2] (mm)	A/P[3]
Fool Creek - Precipitation data from Fool Creek Tower							
1967	3.5	235	288	53	280	79	0.97
1968	3.4	176	234	58	232	48	.99
1969	3.7	246	303	57	308	64	1.02
1970	4.4	321	389	68	376	53	.97
1971	5.1	324	390	66	401	91	1.03
Cabin Creek Precipitation data weighted by Thiessen Polygons							
1977	4.0	228	239	11	212	-13	0.89
1978	4.0	309	316	7	335	-2	1.06
1980	4.0	329	337	9	377	53	1.12
1981	4.0	382	383	1	503	103	1.31
1983	4.0	192	201	9	247	7	1.23

[1]Change is WRENSS HP estimated cut uncut water yield.

[2]Change is as estimated with paired basin regression (Fool Creek: Alexander and Watkins 1977; Cabin Creek: Swanson et al 1986).

[3]Actual measured streamflow after clear cutting divided by WRENSS HP estimated flow after clear cutting.

from it. The leeward edge of clearings greater than 10 to 15 tree heights across should therefore be the most vulnerable. On Fool Creek, where clearings ranged from 1 to 6 tree heights across, little blowdown occurred (Alexander 1967). I think that the Fool Creek results are indicative of what one should expect elsewhere provided the uncut stand is wind firm. With small clearings such as at Fool Creek, one must be careful in locating cutting boundaries if he wishes to take advantage of terrain situations that limit windthrow.

Watershed management cannot be effectively planned and implemented without the involvement of individuals trained in forest hydrology. There will always be a great deal of judgment in any management prescription. Research has provided good tools, but they are not "cook book" techniques. The application of methods to optimize timber harvesting patterns in specific watersheds must always be conditioned by local climatic and topographic conditions.

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Natural and Anthropic Factors as Determinants of Long-term Streamwater Chemistry

Robert Stottlemyer[1]

Abstract--Watersheds of the Fraser Experimental Forest have >30-year hydrologic records and 10 years of stream chemistry data. Seasonal precipitation inputs of K^+ and NO_3^- may affect stream chemistry, but H^+ inputs do not. Long-term stream ion concentration trends appear related to surface water passing through soil macropores. Tree removal has a pronounced effect on increasing watershed NO_3^- loss.

The use of ionic balances is a valuable tool to assess impact of natural and man-caused disturbance. However, much research is needed to identify those factors or processes responsible for natural variation in ion budgets and relationships between ionic concentration and streamwater discharge. A number of recent studies discuss ion dynamics in a watershed ecosystem context (Likens et al. 1977, Bond 1979, Lewis and Grant 1979, Driscoll et al. 1987, Stottlemyer and Troendle 1987). While input/output budgets can indicate ecosystem processes and responses to natural and anthropic disturbance, they are limited in defining cause-effect relationships. Few studies describe the relationship of streamwater discharge to ionic concentration in undisturbed watershed ecosystems with simple annual discharge patterns such as at the Fraser Experimental Forest in Colorado. By "simple" is meant an annual hydrograph dominated by one peak resulting from snowpack melt.

Four watersheds in the Fraser Experimental Forest have long-term (> 30 yrs) hydrologic records, about 10 years of streamwater chemistry, and long-term snowpack data. Precipitation shows only minor evidence of contamination. These attributes provide a base for examining possible mechanisms responsible for observed change in streamwater chemistry and discharge.

This paper looks for watershed responses to natural and controlled human disturbance as indicated by change in streamwater chemistry and watershed input/output budgets. The data are largely preliminary, taken from studies currently underway. Four questions in particular are examined: (1) In small, high elevation Rocky Mountain watersheds significant long-term trends in streamwater ionic concentration can be induced by the timing of snowpack moisture loss and soil perturbation by freeze-thaw (Stottlemyer and Troendle 1987). (2) Despite considerable variation in input/output ratios and stream ionic concentrations, general patterns of nutrient concentration and flux occur during large increases and decreases in stream discharge. (3) When annual peak snow melt is preceded by a small initial release (10+ cm H_2O) the soil water table is raised sufficiently so that subsequent major melt passes through near-surface soil macropores (Driscoll et al. 1987). The chemistry of this meltwater reflects that derived from contact with soil exchange sites, decomposition products, and possibly solutes within the snowpack. Variation in the pattern of snowpack melt has significant effects on annual watershed discharge of ionic species independent of annual precipitation or streamwater discharge. (4) The effect of anthropic disturbance on small basin ionic yield, as through small plot or partial cutting, is considerably influenced by plot size, its effect on snowpack accumulation and timing of melt, and topographic aspect of the basin.

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Site Description

The Fraser Experimental Forest, established in 1937, is about 137 km west of Denver, Colo. A detailed description of the experimental watersheds can be found in Stottlemyer and Troendle (1987) and Alexander and Watkins (1977). Soils descriptions and maps are provided by Retzer (1962). Four primary watersheds are currently under study: Fool Creek, East St. Louis, Lexen and Deadhorse. This paper mainly addresses data from the conterminous Lexen (127 ha) and Deadhorse (278 ha) watersheds (fig. 1).

Road building in the Deadhorse watershed began in 1970-71 with construction of access roads to the North Fork and Upper Basin weir sites. Additional access and spur roads (2.8

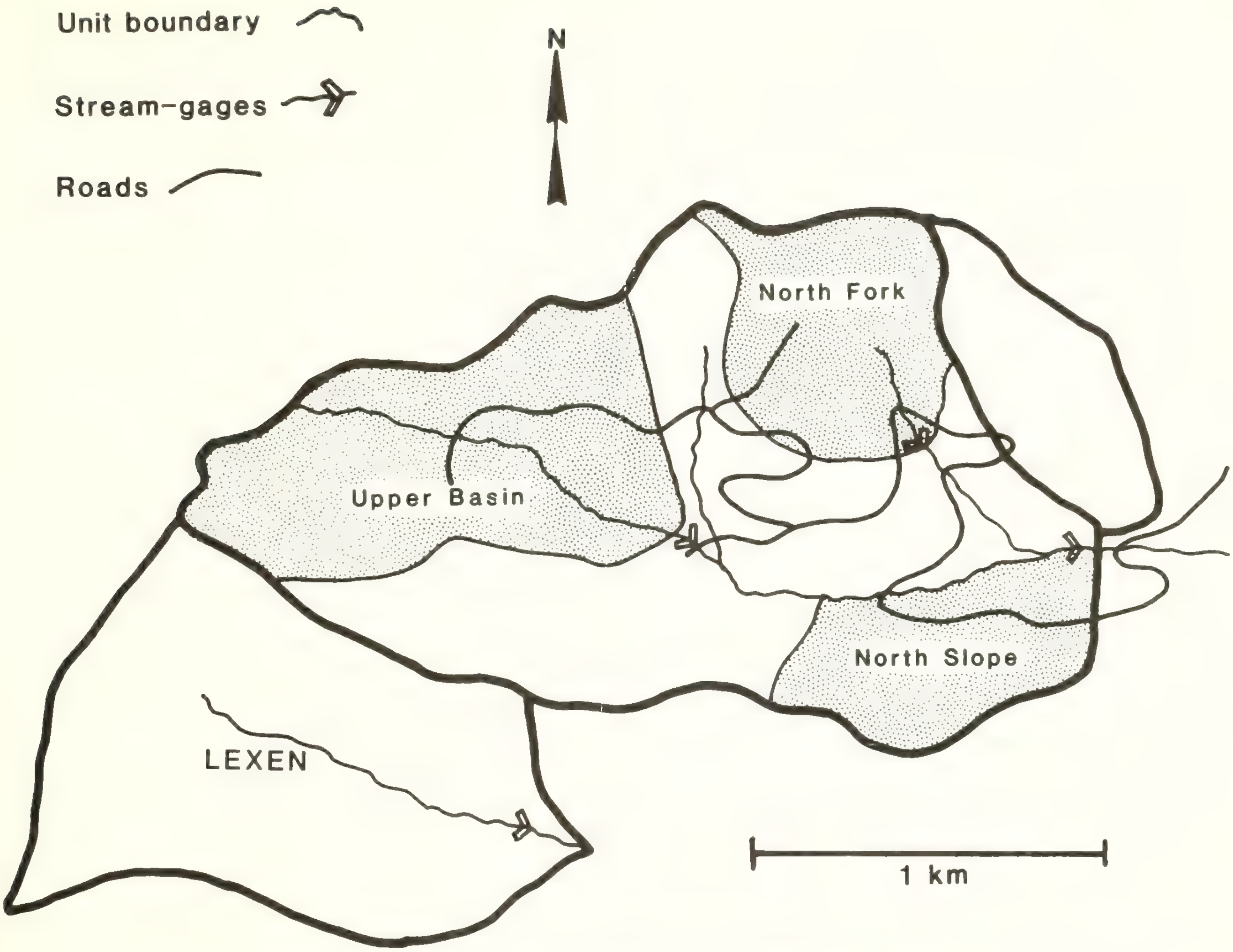

Figure 1.--The Lexen Creek and Deadhorse Creek watersheds and subbasins, Fraser Experimental Forest.

km) were built in 1976 to harvest the North Fork, 2.4 km were built in 1977-78 to harvest the North Slope, and 3 km built in 1981 to harvest the Upper Basin. Total area disturbed in road building was 9 ha (Troendle and King 1986). The first subdrainage timber cutting occurred in 1977 in the North Fork. This was followed by harvesting the North Slope in 1980-81, and the Upper Basin in 1983-84. Additional details of the treatments can be found elsewhere (Troendle and King 1986).

Methods

Streams have been sampled in 1965, 1970-71, and 1982-1987. Streams were sampled just above the gaging station (120° "V" notch weir, digital stage height recorder) and stilling pond (concrete base and weir support, log walls) on a weekly basis from approximately late April to October. On occasion streams have been sampled during winter, but streamwater discharge is so low (mean 0.02 $L \cdot s^{-1} \cdot ha^{-1}$) and unchanging that intensive winter sampling is usually not warranted.

Filtered (0.45 μm) samples are sent refrigerated to Michigan Technological University for ion determinations. Cations and anions are analyzed on an automated Dionex Model 2020 ion chromatograph (IC). Details of quality assurance procedures, field sampling procedures and laboratory analyses are documented elsewhere (Stottlemyer 1987a, Stottlemyer and Troendle 1987).

Precipitation quality is measured weekly at the Experimental Forest Headquarters using an Aerochem Metrics event precipitation collector. Field sampling follows the National Atmospheric Deposition Program (NADP) protocol. Samples are processed in the same manner as stream samples. Daily precipitation quantity is recorded by use of a standard Belfort recording raingage. An additional Aerochem collector was installed at the top of the Lexen watershed in 1987.

Over 20 years of snow course data exist for the major watersheds. In 1985 we began to monitor snowpack chemistry at peak moisture content and with snowpack aging. To date monitoring has been confined to the Lexen, Deadhorse and Upper Fool or Alpine watershed. Change in snowpack ionic content during spring melt has been monitored in proximity to the weather station at Experimental Forest Headquarters. In 1980 snow monitoring plots were established in mature spruce-fir near West St. Louis Creek. The objective of this

Table 1.--Mean annual precipitation ion input ($eq + ha^{-1}$) for period 1984-86 for the Fraser Experimental Forest and National Atmospheric Deposition Program (NADP) stations in the state of Colorado.

Ion	Fraser	Mesa Verde	Sand Spring	Manitou	Rocky Mtn. Lock Vale	Rocky Mtn. Beaver Meadow
Ca^{+2}	104(103)	258(613)	128(245)	96(135)	177(188)	80(84)
Mg^{+2}	35(49)	43(55)	39(80)	29(40)	57(70)	26(30)
K^{+}	32(37)	8(12)	7(15)	8(13)	14(19)	9(19)
Na^{+}	60(75)	40(64)	40(100)	28(38)	64(91)	33(47)
NH_4^{+}	40(35)	48(56)	54(62)	48(72)	102(146)	62(76)
H	62(56)	80(105)	39(50)	47(47)	109(109)	48(65)
NO_3^{-}	82(48)	114(98)	104(128)	108(121)	194(190)	91(72)
SO_4^{-2}	113(81)	195(196)	140(184)	116(118)	261(232)	113(97)
Cl	54(47)	32(41)	30(54)	22(31)	51(48)	25(29)
Mean Cm ppt	67(25)	54(9)	43(3)	40(7)	117(12)	44(2)
N	81	135	144	128	127	142

study was to look at the effect of four-tree length openings on snowpack accumulation. Three 1-ha conterminous plots, one cleared (treatment), one upwind (control), and one downwind of the cleared plot have been monitored. Each plot has a grid of 15 snowpack sampling stations. In early April 1987, we sampled all stations for snowpack moisture and ionic content. Our objective was to estimate canopy modification of snowfall quality and quantity.

The computation of input/output budgets for dissolved inorganics and the statistical methods used are detailed elsewhere (Stottlemyer and Troendle 1987).

Results and Discussion

Precipitation and Streamwater Chemistry

Calcium is the dominant cation and SO_4^{-2} the dominant anion in incident wet precipitation (table 1). Concentrations of H^+, NH_4^+, NO_3^-, and SO_4^{-2} are quite low while K^+ is high in concentration relative to NADP stations in Colorado.

Volume-weighted concentrations of ions in precipitation change little seasonally (fig. 2). Potassium and NO_3^- show the most increase in summer (July - September). The increase is sharpest for K^+ which suggests increased precipitation concentration due to gains in airborne dust following regional loss of snowpack. Hydrogen and SO_4^{-2} reach highest concentration in February and December respectively. Precipitation concentrations of Ca^{+2} and K^+ equal those of NO_3^- and SO_4^{-2} except in late winter when the H^+ input reaches its maximum.

Precipitation concentration and input of all ions except K^+, H^+ and NO_3^- are small relative to stream concentrations and output. The relatively low input of H^+ to these watersheds is retained in the terrestrial component (Stottlemyer and Troendle 1987). The low streamwater acidity reflects the strong buffering capacity of terrestrial components. On an annual basis K^+ input is conserved and NO_3^- input strongly conserved (Stottlemyer and Troendle 1987).

Precipitation inputs to Lexen Creek are about 20% greater than for Deadhorse due to the higher mean elevation of Lexen (C. Troendle, US Forest Service Rocky Mountain Forest and Range Experiment Station, personal communication). However, annual discharge from Lexen exceeds Deadhorse Creek by 43% (Troendle 1983) which probably reflects increased evapotranspiration from Deadhorse with its lower mean elevation.

The annual cycle of streamwater discharge dominates trends in volume-weighted streamwater chemistry (figs. 2 - 5). Daily within-stream ion concentrations generally are most variable during high spring streamwater discharge (figs. 2 and 5). This is especially true for H^+ and NO_3^- (fig. 2). Potassium, H^+ and SO_4^{-2} are the most variable earlier in the snowpack melt period (fig. 6). Summer storms are rarely reflected in watershed hydrographs (fig. 5) and have little or no effect on streamwater chemistry. Processes that may affect seasonal streamwater ionic concentrations, but which have not yet been specifically examined, include the following. High NO_3^- concentrations in spring precipitation could affect stream NO_3^- concentrations during snowpack melt, and the late summer precipitation concentrations could be reflected somewhat in fall stream chemistry. Lowered biological activity in fall could complement precipitation concentrations and help account for the observed increase in stream NO_3^- concentration.

The year-to-year variability in snowpack amount, density, and freeze-thaw period is considerable. From 1970 to 1986 snowpack moisture content in Lexen Creek on or near April

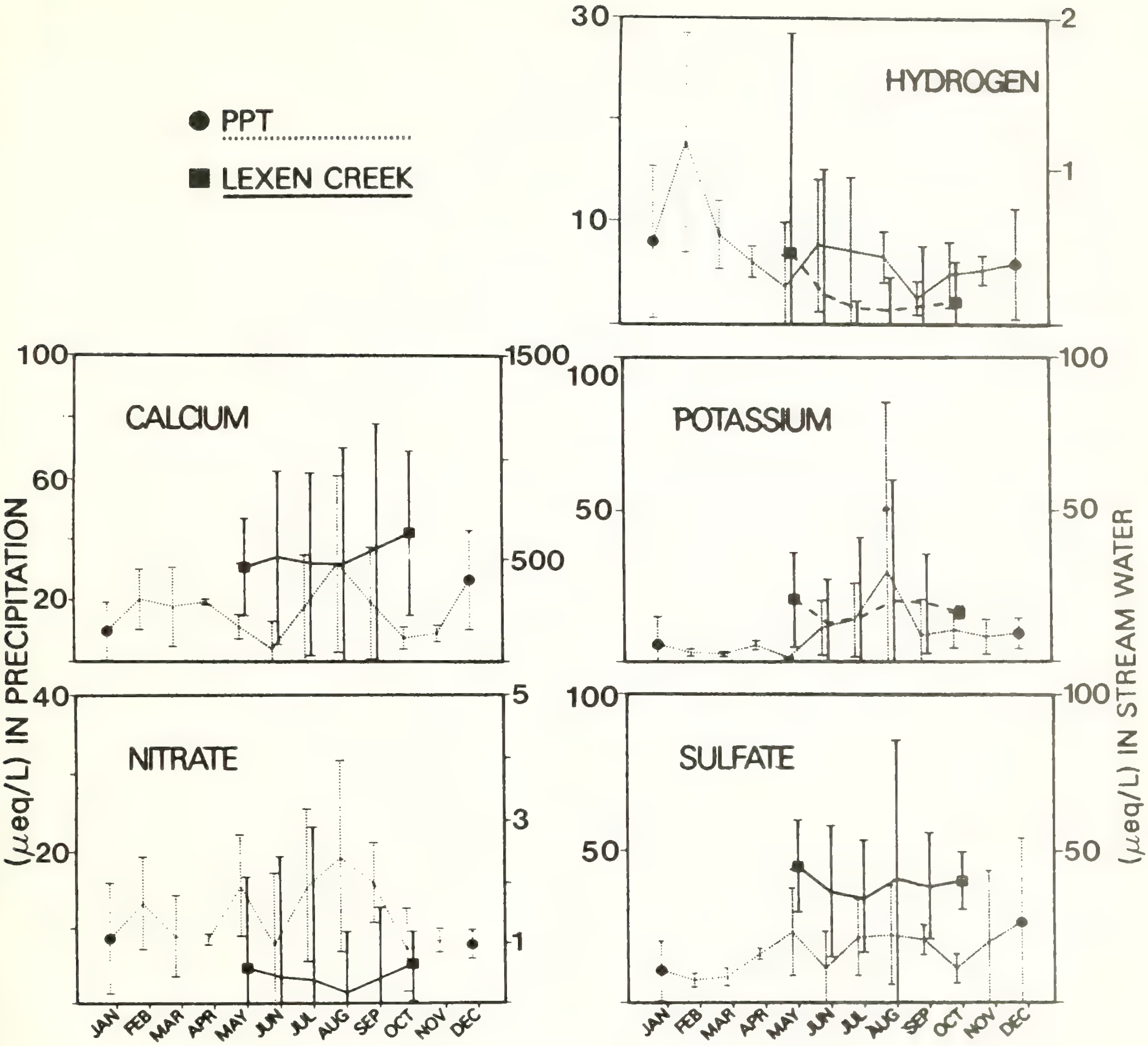

Figure 2.--Volume-weighted mean monthly concentrations for selected ions in wet precipitation (1983-86) and Lexen Creek streamwater (1982-86), Fraser Experimental Forest. The vertical lines for each month represent one standard deviation.

1, the date of estimated mean maximum snowpack moisture content, has varied from 16.6 to 61.5 cm H_2O with a mean of 40.2 ± 11 cm. Ion concentration in snowcores collected in openings near Headquarters from 1984 - 1986 averaged 20 ± 21, 2.5 ± 2.5, 4.9 ± 3.4, 5.7 ± 3.1 and 7.9 ± 8.2 $\mu eq \cdot L^{-1}$ for Ca^{+2}, K^{+}, H^{+}, NO_3^- and SO_4^{-2}, respectively.

The forest canopy is a major factor in altering both the quantity and quality of snowfall reaching the forest floor (Fahey 1979, Cadle et al. 1984). In the snow plots adjacent to West St. Louis Creek, sampled in late March 1987, canopy interception of snowfall amount was 38% (table 2). Despite such interception, throughfall solute addition to incident precipitation resulted in K^+ and H^+ solute loads in the snowpack beneath the forest canopy exceeding those of the clearing. Weighted ion concentration of $K+$, $H+$, and SO_4^{-2} in snowpack beneath the forest canopy exceeded that in the opening.

Snowpack solute content and especially snowpack melting patterns affect trends in streamwater chemistry and ion output (Driscoll et al. 1987, Fahey 1979). At Fraser Experimental Forest change in streamwater ionic concentrations of Ca^{+2} from 1965 through 1986 show a significant increasing trend ($p<0.01$, Kendall's tau, figs. 4 and 5). There was a similar

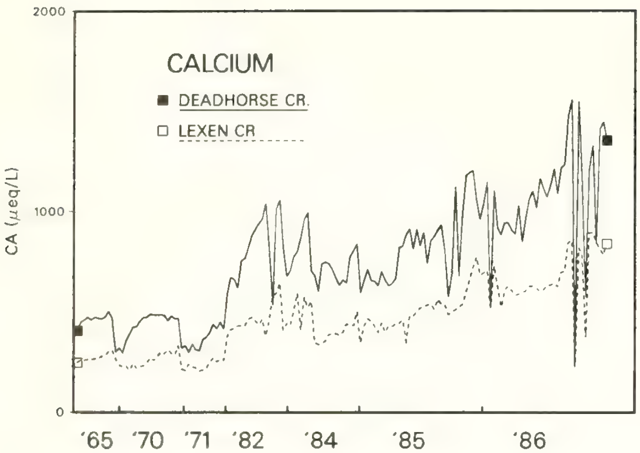

Figure 3.--Time trend of Ca^{+2} concentration ($\mu eq \cdot L^{-1}$) for Deadhorse and Lexen Creeks for the period of study.

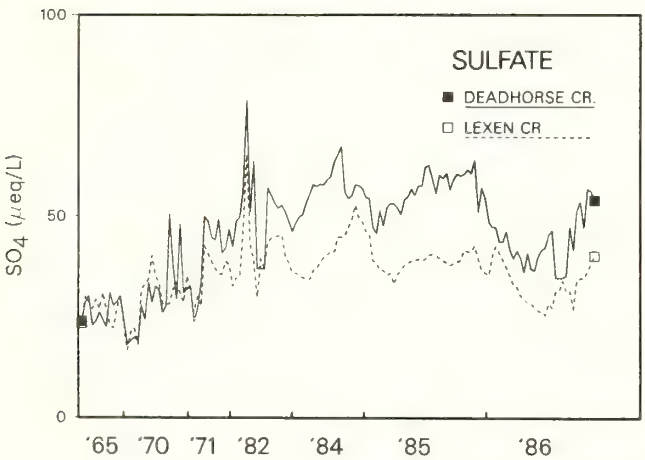

Figure 4.--Time trend of SO_4^{-2} concentration ($\mu eq \cdot L^{-1}$) for Deadhorse and Lexen Creeks for the period of study.

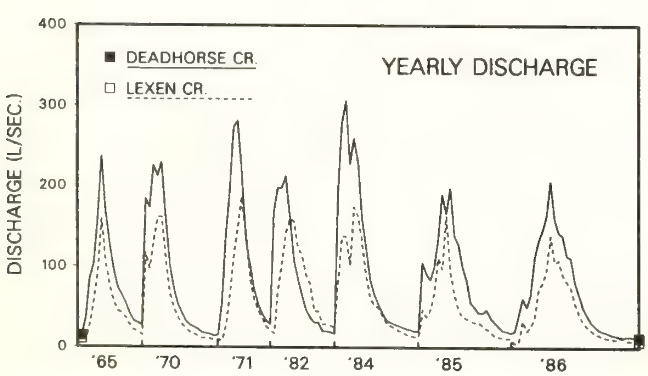

Figure 5.--Stream discharge ($l \cdot s^{-1}$) from Deadhorse and Lexen Creeks from May to September for years shown.

Table 2.--Ion concentration ($\mu eq \cdot l^{-1}$) and snowpack content ($eq \cdot ha^{-1}$) for selected chemical species, snow plots on Short Creek adjacent West St. Louis Creek, March 31, 1987. D = downwind plot, T = treatment (clearcut), and C = control or upwind plot.

	Downwind	Treatment	Upwind
Amount (cm H_2O)	15.8 . 3.9	26.8 . 2	17.5 . 4.5
Volume-weighted mean concentration:			
K^+	10.2	4.6	7.7
H^+	4.8	2.3	4.5
NO_3^-	4.6	7.6	2.6
SO_4^{-2}	11.0	9.4	10.6
Snowpack content (eq/ha)			
K^+	16.2	12.3	13.4
H^+	7.5	6.1	7.8
NO_3^-	7.3	20.2	4.5
SO_4^{-2}	17.4	25.1	18.6

significant trend for SO_4^{-2} up through 1985. There has been no significant trend in precipitation amount or streamwater discharge over this period. This trend in streamwater chemistry appears to be related to natural factors, in particular the pattern of snowpack melt and the relationship of ion concentration to streamwater discharge. The years 1984 and 1986 are included in this trend in ionic concentration yet peak and total annual runoff in 1986 was but a fraction of 1984. This suggests that these two variables, peak snowpack moisture content and total annual runoff, are not major factors responsible for the observed trend in stream ionic concentration. However, in both 1984 and 1986 prior to any increase in stream discharge there was a rise in groundwater level (Troendle, unpublished data). I present the following possible explanation. Spring runoff consists of water from two sources: (1) an initial high ion concentration mini-pulse as the first melt water raises the groundwater stage slightly increasing, through piston action, its flow into the stream, and (2) streamflow dominated by lateral movement in near-surface soil macropores. The chemistry of this second phase is dominated by ions (Ca^{+2}, NO_3^- SO_4^{-2}) released from mineralized organic material and exchange sites in near-surface soils. The relationship between ion concentration and stream discharge changes with change in melt water pathway. This appears to be the process underway in other regions also (Driscoll et al. 1987, Stottlemyer 1987b).

In sum, it appears possible that the significant long-term trends observed in both weighted and unweighted (see Stottlemyer and Troendle 1987) stream ionic concentrations of Ca^{+2} and SO_4^{-2}, and the variation seen in total annual cation discharge versus total annual streamwater discharge (Stottlemyer and Troendle 1987) are due principally to the relationship between stream ionic concentration and discharge. And this relationship is much influenced by any snowpack melt pattern which maximizes water passage through soil macropores. This subject is the focus of continuing ongoing research at the Fraser Experimental Forest.

Factors Regulating Stream Ionic Concentration Patterns

To obtain additional understanding of possible factors regulating stream ionic concentrations, I plotted ion concentration against streamwater discharge by date for 1985-86 in Lexen and Deadhorse Creeks (fig. 6, only 1986 Lexen data shown). Most of the annual variation in ion concentration appears related to change in streamwater discharge. Immediately preceding snowpack melt in 1985 and 1986, streamflow appeared to continue a slight decline and ionic concentration to increase (fig. 6). This ion concentration increase probably reflects the decline in stream water discharge, but regressions of ion concentration against stream water discharge do not account for all the concentration increase (Stottlemyer and Troendle 1987). It is probable that some initial snowpack melt, through "piston action" on deeper soil water, forced a pulsed ionic input from groundwater to the stream without a proportional increase in runoff. Except for Ca^{+2} all ions produced a clockwise plot by date with higher concentrations during the rising hydrograph than during its recession. As a percentage of mean ionic concentration NO_3^- showed the greatest difference between the rising and falling sides of the annual discharge curve followed by K^+ and SO_4^{-2} (fig. 6). Summer and early fall variation for K^+ and NO_3^- may be reflecting change in biological uptake of these ecologically important ions. The SO_4^{-2} trajectory, which for 1986 is unique among the ions analyzed, appears to be reflecting simple dilution on the rising hydrograph. Its relationship to date during the declining hydrograph is more difficult to explain, but could indicate limited seasonal retention through soil adsorption and biological uptake.

There are additional differences among ion concentration trends with date and stream water discharge, however, which could explain some of the multi-year change in ionic concentration. Calcium shows little change in ionic concentration

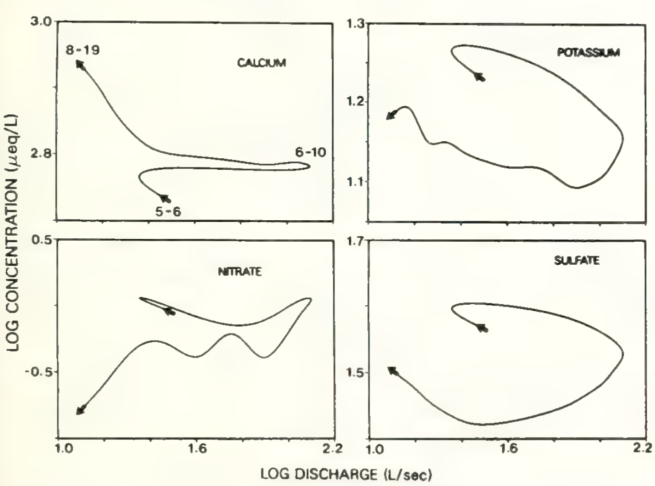

Figure 6.--Time, stream discharge and ionic concentration plots for Ca^{+2}, K^+, NO_3^- and SO_4^{-2} for Lexen Creek in 1986. Ion concentration is plotted against total daily stream discharge with the points joined by increasing date beginning in late April and ending in early October with peak discharge on or about June 10.

over most of the range of increasing stream water discharge. This suggests that Ca^{+2} losses are more a factor of the percentage of annual discharge occurring at high flow rather than total annual flow, total precipitation, or total snowpack moisture or ionic content. Thus, during years of sharp snowpack runoff, as in 1984 and 1986, Ca^{+2} concentration and total discharge would be disproportionately higher than predicted from total annual streamwater discharge.

Nitrate concentrations actually increase with high stream discharge. During peak snowpack runoff biological uptake is still limited. If meltwater is passing through surface soils, it could be picking up mineralized nitrogen along with any contained in the snowpack melt. Again, any natural or man-induced factor which might promote and/or sustain runoff at higher flows would increase both the concentration and output of NO_3^-.

Sulfate also shows little change in ion concentration as the hydrograph increases. Annually its range of concentration change is small. Also, it is the only ion showing a decrease in concentration with decrease in streamwater discharge.

Calcium and SO_4^{-2} are the dominant ions in precipitation and the snowpack, and Ca^{+2} and HCO_3- are the dominant ions in streamwater. Streamwater runoff in 1984 and 1986 was especially high relative to precipitation. This, coupled with only slight change in concentration during the rising and falling hydrograph would account for the significant long-term increase in stream volume-weighted ionic concentration of Ca^{+2} and possibly SO_4^{-2} (figs. 4 and 5).

Except for NO_3^- I found very similar patterns for the main Deadhorse gauging station (Deadhorse Main). These results, along with the findings of others (Bond 1979, Likens et al. 1977), suggest that use of such data comparisons to develop a generalized understanding of the relationship between ionic concentration and stream discharge is effective. However, I have also done such data comparisons for watershed studies in the Upper Great Lakes, and generalizations drawn appear limited to only regional application.

Ion Yields Following Timber Harvest

The assessment of watershed response to vegetation manipulation in subbasins of Deadhorse was confined to those years where complete stream water chemistry exists (tables 3 - 5). Unfortunately, complete chemistry for Deadhorse North prior to and during its treatment does not exist.

Precipitation during and following tree harvest was outside the 95% confidence limits of the pre-treatment period (table 3). The ratio of runoff/precipitation (R/P), plus R/P expressed as a percent of the pre-treatment years, shows a similar response among watersheds except for the increased runoff from the Upper Basin. Precipitation data for the Upper Basin are not available prior to 1982 and confidence limits cannot be calculated for annual R/P, but it appears that inputs were higher in this subbasin. The high Upper Basin runoff probably reflects snow which blows into the basin from the west and is

Table 3.--Mean annual precipitation (ppt) and stream discharge in centimeters prior, during and after treatments for Deadhorse Main, Upper Basin, and North Fork watersheds, and Lexen Creek (control). Values in parentheses are standard deviations. Mean values outside the pre-treatment period 95% CI are underlined.

	Lexen Creek			Deadhorse Main			Deadhorse North			Deadhorse Upper Basin		
	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86
Ppt.	82(2)	98	65	68(1.8)	81	54	62(4.2)	74	49	79	105	61
Runoff	53(2.6)	45	54	35(2.2)	36	35	34(2.9)	34	35	51	66	67
Run/ppt	0.65	0.46	0.83	0.51	0.44	0.65	0.55	0.46	0.71	0.65	0.63	1.10
R/P as %	100	71	128	100	86	127	100	84	129	100	97	169

Table 4.--Mean annual concentration (.eq . l^{-1}) of major ions prior, during and after treatments for Deadhorse Main, Upper Basin, and North Fork watersheds, and Lexen Creek (control). Values in parenthesis are standard deviations. Mean values outside the control 95% CI are underlined.

	Lexen Creek			Deadhorse Main			Deadhorse North			Deadhorse Upper Basin		
	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre 1982	During 1984	Post 85-86
Ca^{+2}	238(25)	469	528	354(62)	747	873		779	884	776(130)	899	909
Mg^{+2}	182(20)	109	142	253(33)	171	214		200	221	177(29)	197	225
K^{+}	16(5)	15	15	20(11)	26	24		24	21	18(7)	24	19
Na^{+}	98(37)	51	62	97(57)	65	70		77	75	58(12)	51	59
NH_4^{+}	----	3.9	1.0	----	0.4	1.3		1.5	1.2	1.8(5.9)	0.7	1.5
NO_3^{-}	0.22(.13)	0.4	0.5	0.50(.25)	0.9	1.6		4.8	4.2	0.4(0.6)	1.8	2.6
SO_4^{-2}	31(10)	39	37	36(12)	49	47		50	49	35(5)	37	38
n	44	38	59	51	40	70		30	70	15	23	71

Table 5.--Annual discharge (eq . ha^{-1}) of major ions prior, during and after treatments for Deadhorse Main, Upper Basin, and North Fork watersheds, and Lexen Creek (control). Values in parentheses are standard deviations. Mean values outside the control 95% CI are underlined.

	Lexen Creek			Deadhorse Main			Deadhorse North			Deadhorse Upper Basin		
	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre .65,70-71	During 82-84	Post 85-86	Pre 1982	During 1984	Post 85-86
Ca^{+2}	1261(130)	2110	2851	1239(135)	2833	3056		2649	3094	3958(707)	5933	6090
Mg^{+2}	965(108)	490	767	886(134)	616	749		680	773	903(161)	1300	1508
K^{+}	85(36)	68	81	70(31)	94	84		82	74	92(59)	158	127
Na^{+}	519(245)	230	335	340(228)	234	245		262	262	296(88)	337	395
NH_4^{+}	--	18	5.4	--	1.4	4.6		5.1	4.2	9.2(56)	4.6	10.1
NO_3^{-}	1.2(.6)	1.8	2.7	1.7(.9)	3.2	5.6		16	15	2.0(2.6)	12	17
SO_4^{-2}	164(38)	176	200	126(31)	176	164		170	172	178(30)	244	255
n	44	38	59	51	40	70		39	70	15	23	71

difficult to quantify. During the pre-treatment period, the lower R/P for Deadhorse Main, relative to Lexen, probably reflects the higher evapotranspiration from Deadhorse. Compared to Lexen Creek, the Deadhorse watershed and its subbasins had higher R/P values during disturbance relative to pretreatment R/P values. This was most evident for the Upper Basin. However, the data for Deadhorse Main and Deadhorse North need some qualification since the 1982-84 results follow the disturbance of Deadhorse North by four years. Runoff immediately following disturbance was even higher than reported here (Troendle 1983). Except for the Upper Basin, the disturbed Deadhorse North and Deadhorse Main now appear to have recovered in terms of R/P relative to the undisturbed Lexen watershed.

Similar comparisons of volume weighted streamwater ion concentration (table 4) during this period provide additional evidence as to what factors may be responsible for longer-term trends in streamwater chemistry. Since no stream chemistry data were collected from Deadhorse Main or Deadhorse North during the actual disturbance of Deadhorse North (1977) and there are no pre-treatment chemistry data for Deadhorse North, post-treatment comparisons for Deadhorse North are made with pre-treatment data from Deadhorse Main.

Except for Mg^{+2} and occasionally K^{+}, most ions showed increased concentration during and following the treatment periods. Lexen Creek, the control watershed, had higher concentrations of Ca^{+2} and SO_4^{-2} during and following disturbance in the Deadhorse subbasins (table 4). The possible causes of this have been discussed earlier in relation to the long-term trend of increasing Ca^{+2} and SO_4^{-2} in both Lexen and Deadhorse. Lexen Creek K^{+} concentrations are low relative to the disturbed Deadhorse drainages. Nitrate concentrations increased markedly in the disturbed Deadhorse basins, especially Deadhorse North. The cutting of Deadhorse North began in 1977. Since the 1982-84 concentration data for Deadhorse North actually follow the disturbance of this drainage by four years, the concentration during disturbance was probably higher than observed here. The increase in NO_3^- can be attributed to reduced biological uptake (Knight et al. 1985), increased nitrification (Vitousek et al. 1979), and reduced canopy interception of snowfall resulting in a larger snowpack and quicker runoff (Troendle 1983) which would promote removal of the very soluble NO_3^- from the soil (Vitousek et al. 1979).

Ion yield data (table 5) show the importance of the differing relationships among ion concentration and streamwater discharge discussed earlier (fig. 6). The yield of Ca^{+2} and Mg^{+2} show little evidence of restored ecosystem conservation. The yield of K^{+} from all Deadhorse stations, when compared to Lexen, suggests some but not complete recovery. Yields at Deadhorse Main primarily reflect trends observed in the Upper Basin. The yield of Ca^{+2} and SO_4^{-2} from this basin appears in line with the increased runoff during and following disturbance.

Except for the Upper Basin, there are only limited pretreatment data for NH_4^{+}. Ammonium appears strongly conserved during treatment in this subdrainage, and resumes pretreatment levels after treatment.

Of the ions I analyzed, NO_3^- clearly is the most responsive to disturbance. However, yields vary widely even for the undisturbed Lexen watershed. Again this probably reflects, at least seasonally, precipitation inputs and reduced biological uptake especially in the fall (fig. 2). The only watershed showing some, but minimal, evidence of restored NO_3^- conservation following disturbance is Deadhorse North, but it must be remembered that the data for 1982-84 follow disturbance by four years. The Upper Basin appears to still be losing high amounts of NO_3^- two years following disturbance, and this probably accounts for the trend in yield from Deadhorse Main. Precipitation inputs of NO_3^- were above average in 1984, due mainly to high precipitation amounts. Nitrate loss from the Upper Basin could also be the result of reduced biological uptake, increased nitrification, the increased precipitation runoff, a larger percentage of runoff occurring at high discharge, and the relationship of NO_3^- concentration to stream discharge (fig. 6).

The trends in yield of SO_4^{-2} appear little influenced by disturbance. However, yields from all disturbed watersheds exceed those observed in Lexen. Yield from Deadhorse Main is again influenced by yields from the Upper Basin, which appear to be reflecting differences in precipitation input and higher mean runoff.

Summary

It appears from these preliminary data that the primary factors controlling stream concentrations of ionic species in Fraser watersheds are those related to weathering interacting with natural disturbance in upper basins, precipitation amount and timing (pattern) of snowpack runoff, elevational influences on evapotranspiration, biotic uptake, nitrification, and biomass accumulation of nutrients. Seasonal precipitation inputs of K^{+} and NO_3^-, when concurrent with a decrease in biotic uptake, may be reflected in stream chemistry, but inputs of H^{+} appear to have little or no direct effect on streamwater chemistry.

The long-term trend observed in increasing stream concentrations of Ca^{+2} and SO_4^{-2} appears related more to the pattern of snowpack melt and the amount of runoff passing through soil macropores rather than the annual amount of precipitation or the peak moisture content of the snowpack. However, I have no direct evidence yet to support this hypothesis.

Tree removal has a pronounced effect on increasing watershed NO_3^- loss. This probably is due to reduced biotic uptake and increased nitrification. The loss appears to also be related to any factor, such as slope or aspect, which might increase the snowpack moisture content and its rate of melt.

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The Potential of Subalpine Forest Management Practices on Sediment Production

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Abstract--The potential effect of subalpine forest management practices on sediment production is low when best management practices (BMPs) are implemented. Instream sources are the largest contributor of sediment, while off site erosion is limited due to the physical characteristics of the subalpine environment.

Management of water quality in a forest must consider all activities in watershed forest practices and other nonpoint sources in combination with natural processes (Packer 1967). Soils and geology are the foundation of the forest ecosystem. Soil properties which affect erosion processes in a watershed are of primary consideration.

Soils developing in the subalpine region are influenced by short growing seasons and relatively high amounts of precipitation received as winter snowfall and spring snowmelt. These soils are generally forming in residuum and colluvium derived principally from gneiss, schist, and/or granite and are, therefore, coarse textured. Soils have high infiltration capacities and moderate permeability; thus overland flow is rare. Cryorthents, Cryoboralfs, and Cryochrepts are the predominant great groups found in the subalpine region. Tolerable soil loss for the subalpine environment has been identified as 2-5 tons/acre/year, depending on the specific soil group. Watersheds with erosion rates above this level are identified by the Forest Service as critical (USDA Forest Service 1981).

The sediment load of streams (both suspended and bedload) is determined by such characteristics of the drainage basin as geology, vegetation, precipitation, topography, and land use. The sediment enters the stream system by erosional processes. To achieve stream stability, an equilibrium must be sustained between sediment entering the stream and sediment transported through the channel. A land use activity that significantly changes sediment load can upset this balance and result in physical and biological changes in the stream system (State of Idaho 1987).

The existing form and characteristics of streams have developed in a predictable manner as a result of the water and sediment load from upstream. Natural channels are self formed and self maintained. Both water and sediment yields may change due to silvicultural or other land use activities upstream. Increases in water and sediment yields should be evaluated in terms of potential effects on channel stability.

Sediment routing and storage are particularly important components in the transport process of sediment loads through the stream system. They are critical to the quantification of short and long term impacts of land use activities on stream channels and beneficial uses. However, the storage and routing processes are highly variable and exhibit non steady state behavior. Continuously evolving relationships involving sediment supply and energy availability are used to estimate sediment discharge changes as the result of land use activity.

Maintenance of stream sediment transport (and minimizing vegetation growth within the channel) should retain the channel's capability for passing floodflow discharges. This physical concept is used to determine channel maintenance flows that will maintain stream channel stability for the orderly conveyance of water from and through the National Forests (USDA 1985).

Results from studies in subalpine watersheds have identified correlations between annual peak discharge and annual sediment discharge. A similar relationship between total annual flow and annual sediment discharge has also been determined. A major portion of the sediment load is composed of bed material derived from streambank erosion and channel degradation (Stednick, unpublished data, among others). Substantial increase in runoff may upset channel stability, increasing turbidity and sediment concentrations.

Forest practices have the potential to affect water quality in a number of ways (Sopper 1975). Accelerated sedimentation has been identified as the primary water quality problem related to forest management in the western United States. Activities associated with timber harvest, yarding, and road construction and maintenance result in disturbance of soils and vegetation and may increase soil susceptibility to erosion. These disturbances may alter the hydrologic cycle, generating

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more overland flow for detachment and transport of sediment. Forest harvesting has been moving towards progressively steeper sloped lands in recent years, intensifying the problem (King and Gonsior 1980).

Roads

Roads are the primary source of sediment from forested watersheds. It is estimated that 90% of the sediment production from timber harvest can be attributed to roads (Megahan 1972). Sediment yield increases of two to three orders of magnitude over undisturbed sites have been observed (Megahan and Kidd 1971). The magnitude of sediment contributions from roads vary greatly, depending on the soil type, geology, topography and climate characterizing the particular site and road construction practices. Roads on gentle to moderate slopes and stable topography have a low potential for contributing sediment when properly constructed and maintained. However, roads located adjacent to streams, on steep slopes, and/or unstable topography have a high potential to produce sediment for a long period of time if not properly planned, constructed, and maintained.

Sources of sediment from forest roads are (1) direct movement of soil during construction and maintenance, (2) surface erosion, and (3) mass erosion (Youngberg, et al. 1973, Larse 1970, Fredriksen 1970, Fredriksen 1965). If the road is located so that construction activities cause direct movement of soil into stream channels, then it is likely that future maintenance activities will also contribute sediment, especially if the road encroaches directly upon the stream or riparian zone.

Climate, vegetative cover, slope, and soil characteristics are important in determining sediment yields from undisturbed sites. Road construction alters the latter three and generally increases erosion and transport of sediment for some time (Megahan 1975). Removal of vegetation and the litter layer from soil surfaces exposes soil particles to the energy of raindrop impact, the primary agent of interrill erosion (Meyer, et al. 1975). The reduction in infiltration necessary for stability increases road surface runoff, which may be augmented by overland and subsurface flow from the cutslope and drainage area above it. As flow and the energy associated with it accumulate and become concentrated in channels, rill and gully erosion cause much larger volumes of sediment to be detached and transported. Properly designed roads will minimize concentrations of flow through outsloping and frequent water diversions.

Surface erosion is greatly accelerated during and shortly after road construction. Approximately 84 percent of the total sediment production for a 6 year period was produced during the first year after road construction (Megahan 1972). Once the exposed soil revegetates or becomes armored, surface erosion declines rapidly. Concurrent erosion control during construction with immediate stabilization of exposed soils are needed to minimize surface erosion and sediment contributions.

Two other features of road construction are not found on every segment but may be important in determining the distance of sediment movement. When the road is pioneered, cut timber is temporarily stored adjacent to the road, usually on the downhill (fillslope) side, and occasionally a dip may coincide with one of these log decks, diverting sediment laden water between the logs. The log decks may then act as baffles to reduce flow energy and increase deposition during the period immediately after road construction when sediment movement is greatest.

The stumps from these right of way trees may be disposed of either by burning or by burial. Generally burial is used because it is quicker and easier, occasionally leaving a large area of bare disturbed soil immediately downslope from the road. If high energy runoff is diverted over these burial pits, rill and gully erosion may result. Good management requires burial pits to be discrete relative to the road. Both log decks and burial pits occur infrequently relative to the number of water diversions along the road.

Surface erosion results from raindrop impact on exposed soils and sheet, rill, and gully erosion of unprotected cuts and fills. It is influenced by rainfall/snowmelt characteristics, soil characteristics, topography, and plant and litter cover. The reported magnitude of sediment contributions from roads varies greatly (Campbell 1983, King 1979, Beschta 1978, Krammes and Burns 1973, Brown and Krygier 1971, among others). An evaluation of sediment contributions from surface erosion on jammer roads in the Idaho batholith revealed a 1560 fold increase in sediment production during the year following construction, and a 50 fold increase 3 years later. Approximately 30 percent of the total road erosion was due to surface erosion and 70 percent to mass erosion (Megahan and Kidd 1972).

Sedimentation processes occur on all of the features of a typical road segment (Haupt 1959, Haupt and Finn 1963, Bethlahmy 1965, Bethlahmy 1967, Dyrness 1967, Falletti 1977). The cutslope is a steep bank on the uphill side of the road which consists of relatively stable material which was in place before the site was disturbed. Erosion may occur here if overland flow spills down the cutslope or if subsurface flow emerges from the bank.

The road surface is a bench of highly compacted material where most of the overland flow is generated. This surface is slightly outsloped in order to direct sheet flow to the outer edge of the road, where it can be diverted before concentration of flow occurs. At intervals, dips in the road are placed in order to divert any runoff which may be flowing along the axis of the road. The distance between these dips, or road segment length, determines the total area which may contribute to one of these water diversions.

Road derived sediment reaching the stream course has been shown to decrease exponentially with time since road construction (Megahan and Kidd 1972, King 1979, King and Gonsior 1980). Significantly accelerated surface erosion was observed only during a few thunderstorms immediately following road construction. Re establishment of vegetation is an

obvious factor influencing stabilization but physical processes such as development of pavement and armoring may be involved as well. More easily eroded fine particles are readily transported, and surface erosion decreases as their availability is diminished.

As sediment laden runoff reaches the edge of the roadfill, it is dammed by debris and energy is dissipated by litter and vegetative cover. Windrowing of slash along the toe of fillslopes may aid in controlling erosion and subsequent sedimentation (Cook and King 1983). This reduces the energy available for transport, causing deposition which decreases the distance sediment will be moved. However, the actual processes which describe and the parameters that control the delivery of eroded material downslope are less well understood than those for erosion, and data for sediment delivery are scarce (Campbell 1983, USDA Forest Service 1980). In the discussion of sediment delivery in Water Resources Evaluation of Nonpoint Silvicultural Sources (WRENS), a sediment delivery index is presented with the acknowledgement that data to support the index does not exist, and more research is necessary to establish reliable estimates of sediment delivery (USDA Forest Service 1980). Equations that utilize erodibility indices based on rainfall intensity may be grossly in error when applied to the subalpine environment, since much of the streamflow is from snowmelt (Leaf 1966).

Studies in Idaho indicated that on well designed roads most sediment flows travel less than ten meters from the toe of the fillslope and occur soon after construction (Haupt and Kidd 1965). Buffer strips of ten meters were recommended to capture all of the sediment being transported from the road disturbances. Sediment movements of more than twenty meters have been observed on the Fool Creek drainage of the Fraser Experimental Forest (Troendle 1981).

The problem of road erosion is also related to the density of the road network. Careful planning can help minimize road density. An unplanned road system constructed by the logger at the Fernow Experimental Forest in Colorado occupied 4.8 to 7.0 percent of the area, while a well planned road system on similar topography only occupied 2.5 to 4.6 percent (Mitchell and Trimble 1959). In addition to careful planning, the harvesting system employed largely governs the required road density. Jammer logging may expose 25 to 30 percent of the area as roads while longer cable systems such as a skyline setup may only expose 2 percent of the area (Rice, et al. 1972).

Mass wasting related to roads includes fill and backslope failures, slumps, earthflows, landslides, mudslides, and rockslides (Swanston 1981, Swanston 1976). Surface and mass erosion from roads are related to one or more of the following: removal of protective cover, destruction of soil structure, increases in slope gradients, decreases in infiltration capacities, interception of subsurface flow, decreases in shear strength, increases in shear stress, and concentration of generated and intercepted surface water, and reduced rooting strength (Gray and Megahan 1981, Megahan 1977, Swanston 1970).

It is generally thought that decay of tree roots and the resulting reduction in a soil's shear strength contribute to mass soil movement on high hazard sites (Burroughs and Thomas 1977, Davis 1976). Control of this hazard relates to recognition of the failure potential of an area and regulation of both the yarding system and silvicultural prescription (Brown, et al. 1976, Rothwell 1971).

Steep slopes, relatively shallow soil, and rapid, large volumes of water are generally required for mass wasting to occur (Megahan 1975). However in some situations, prolonged snowmelt and low intensity rainfall events can also contribute to mass wasting. Careful route selection is required to avoid potential problem areas. Mass erosion is not significant in the subalpine environment.

Work in the Idaho batholith led to the conclusion that road design parameters may be important in predicting erosion, but downslope transport of the material was primarily controlled by slope steepness and the type and amount of cover.

Other investigators (Haupt and Kidd 1965) have reported similar trends after measuring sediment movement downslope from cross ditches and in ephemeral channels. While there was much variability between sites, movement downslope had effectively ceased three years after roads had been put to bed, i.e., closed to traffic, water barred, culverts and bridges removed, and allowed to revegetate.

Earlier studies of sediment transport along Fool Creek (Leaf 1966, Leaf 1974) indicated little or no water quality degradation is to be expected from road construction with proper planning, construction and maintenance. A model was fitted to the Fool Creek Watershed based on sediment yield data collected by an in stream sediment trap. This model predicted decreased sediment yield with time, as a function of topographic and road engineering characteristics (Leaf 1974). It did not address the hillslope processes which are involved in determining sediment delivery to the stream.

A set of guidelines for road sediment control were developed for the Northern Rocky Mountain region (Packer and Christiansen 1964) and for roads in Idaho (Megahan 1977). Factors affecting the distance sediment moves downslope were identified as cross drain spacing (road segment length), kinds and spacing of obstructions, cover density, soil particle size distribution, and road age.

Much of the data describing the decrease in sediment yield with time has been collected on roads that were put to bed. In these cases, a dynamic equilibrium evolves from channel stabilization and erosion pavement development. However, roads receiving continuous use may not recover, or response may be much slower, as a result of continued disturbance. This effect has been demonstrated simply by limiting vehicle traffic in areas of the Deadhorse and Fool Creek watersheds in the Fraser Experimental Forest (Troendle 1983).

Sediment contributions from forest roads can be minimized through proper planning route selection, design specifications, construction practices, maintenance and stabilization measures (USEPA 1975). To maintain water quality,

greater attention is being given to soil and geologic characteristics, avoidance of high hazard areas, improved engineering surveys, improved road design and improved construction methods (Clayton 1983, Gardner 1979, Stone 1973). Proper location of roads relative to streams is also essential. However, a strong preventive approach is not always free of failure, and supplemental corrective measures may be required to minimize sedimentation from roads (U.S. EPA 1975).

Standards and guidelines used by the Forest Service include establishment of 30-meter (100-foot) buffer strips along all water courses (USDA Forest Service 1981). Road construction should be scheduled during dry periods with low flow and maintenance activities should be scheduled to avoid prolonged wet periods. Riparian strips have standards and guidelines for basal area reduction, surface disturbance and slash disposal practices (USDA Forest Service 1981).

Harvesting

Timber harvesting and subsequent yarding can increase sediment in streams by increasing surface erosion rates and increasing the risk of mass soil movement (Brown, et al. 1976, Davis 1976). Site disturbance can reduce infiltration rates, and hence, the quantity of overland runoff and related surface erosion.

Methods used for the movement of logs from the stump to a landing can be classified as tractor, cable, aerial or animal. Both aerial and animal yarding are almost nonexistent in the subalpine environment. Tractor skidding is accomplished with either crawler or wheel type units, both of which are frequently equipped with arches for reducing the extent of contact between log and ground.

Site disturbance will vary greatly with the type of skidding or yarding system. Crawler tractors generally cause the greatest amount of site disturbance, followed closely by wheeled skidders, but on some sites use of wheeled skidders can result in more compaction than use of crawler tractors (Davis 1976, Bell, et al. 1974). One method of decreasing the amount of soil disturbed by crawler tractors or wheeled skidders is through careful layout of skid trails (Rothwell 1971). Planning for skidroad location and number can greatly decrease the impact of tractor logging. Cable logging systems will result in less site disturbance, because yarding trails are established to the yarding tower machinery restricted to road surfaces. Cable systems can be ranked in order of decreasing soil disturbance as follows: single drum jammer, high lead cable, skyline, and balloon (Brown, et al. 1976, Davis 1976, Stone 1973). Helicopters and balloons will likely result in minimum site disturbance, but both are costly and subject to operational constraints.

Sediment yields from Fool Creek after logging were relatively large during the years immediately after treatment. Yields in subsequent years were considerably less and not significantly different from the pretreatment means (Leaf 1966). The return of suspended sediment concentrations to pretreatment levels has been best modeled as a negative exponential (Leaf 1974, Megahan, 1980). This time factor should and can be considered in land use planning and design of best management practices.

One of the best methods of controlling the entry of sediment into streams from harvesting on roads is through the use of buffer strips (USEPA 1977, Brown, et al. 1976, USEPA 1975, Bell 1974). Buffer strips have also been shown to be effective in reducing the entry of logging debris into streams and in controlling stream temperature.

The silvicultural prescription implemented by harvesting can influence both water quantity and water quality. Silvicultural prescriptions for the subalpine may include shelterwood, seed tree, clear cutting, and selection (U.S. EPA 1976). Prescription of a particular system will depend upon existing conditions and land management objectives.

Conclusions

Subalpine forest management practices include roading and silvicultural treatments that involve tree harvesting. These practices have been evaluated for nonpoint source water quality impacts. Much of the literature on forest management activities and water quality changes is from the Pacific Northwest and has documented dramatic water quality changes (or impacts). The identified processes are applicable to the subalpine forest, but the observed water quality changes are not. The potential of subalpine forest management practices on sediment production BMPs are implemented is low. Sediment generation may occur from roading and harvesting, however the increase is short lived and often not measurable when best management practices have been utilized. The major portion of the sediment load is derived from in stream sources, i.e., streambank erosion and channel degradation. Suspended sediment concentrations are low in undisturbed subalpine watersheds. Management activities may increase these concentrations for brief time periods, however suspended sediment concentrations and turbidity changes can still meet state water quality standards.

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Watershed Research for Management Needs: Which Way We Ought to Walk from Here

Rhey Solomon[1]

The Fraser Experimental Forest was established in 1937 to study natural plant communities and determine their effects on snow accumulation and water yield changes in response to management of the subalpine forests. The work derived from this experimental forest has served well in providing managers with watershed relationships that help them understand water yield and snowpack processes (Alexander et al. 1985).

However, before we roundly endorse research from Fraser and other experimental forests, let us step back a little and take a more introspective look at where we have been and how we have approached research and the management application of research for the subalpine forest.

I'm going to be a little self-criticizing, only because I feel self analysis is always helpful in keeping on the right track. In this effort, I'll rely on a quote from Alice in Wonderland where Alice is confronted on her walk by the Cheshire cat. Alice, not really knowing where she was or where to go, asked the cat, "Would you tell me, please, which way I ought to walk from here?" The Cat answered with, "That depends a good deal on where you want to go." Alice thought for a while and responded, "I don't much care where." The cat in his wisdom said, "Then, it doesn't matter which way you walk." Alice, being a little concerned, states, "So long as I get somewhere." As a final reply the cat matter-of-factly says, "Oh you're sure to do that if you only walk long enough."

I use this passage from Alice in Wonderland because I feel it parallels, in many respects, the questioning and answering that goes on between National Forest System managers and Research. Management often ask of Research which way it ought to walk. Research properly asks management just where it wants to go. The question to evaluate in today's talk is whether Management has adequately given Research the desired destination (Objectives) or, as like Alice, didn't much care. In the end, as the cat points out, "You're sure to get somewhere if you only walk long enough." Has Research taken Management where it wanted to go, or have we gone down a path getting to some destination but not sure if it's where we wanted to be?

Let's evaluate how well we did in our journey -- did we take a path not really caring where we got to -- or did we more deliberately choose where we wanted to go? I'll start first by expressing an overriding objective or destination for National Forest System management derived from enabling legislation, the Organic Act, which designates the purposes of the National Forests:

> ...For the purpose of securing favorable conditions of water flow, and to furnish a continuous supply of timber....

We often lose sight of this objective, especially when framing questions for Research. We focus on very technical questions. We therefore have to ask ourselves, can we better define and manage for "favorable conditions of flow" today than we could before undertaking research at Fraser and the other experimental watersheds? This is the central theme of my talk today -- do we better understand our basic watershed objective in today's world of simulation models, computer tools, and mapping techniques than we did 50 years ago?

We can start first by looking at how we in the National Forest System have chosen, through our actions and policies, to define "favorable conditions of flow." Typically, favorable conditions of flow have been translated into three component parts, (1) water quality, (2) water quantity, and (3) water timing. Generally, these aspects of favorable conditions of flow have been related to conditions of the land. We have developed a term over the years that has come to encompass all three measures of water as well as land conditions -- this term is "watershed condition."

Using this watershed condition theme, the management issues emerging in the 1930s and 40s were related to off-forest impacts -- flooding, lack of water, debris clogging of irrigation works, and maintaining navigability of streams. How well did research, and more specifically work at Fraser, respond to these issues? The watershed work done at Fraser was primarily aimed at questions dealing with water yield and specifically snowpack management to increase yields and affect runoff timing. Table 1 shows the published watershed research from the Fraser Experimental Forest over the last five decades (Alexander et al. 1985).

As shown in table 1, the work at Fraser was aimed at answering management questions about water yield response. Over the first three decades this research appeared to be steady. However, in the late 70s and on into the 80s this

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Table 1.--Published watershed research from the Fraser Experimental Forest.

	Decade					
	40s	50s	60s	70s	80s	Total
Water Yield	17	20	21	18	8	84
Sediment/Erosion	--	--	2	7	--	9
Measurement	11	2	5	8	--	26

research declined and culminated in a series of papers that, generally, satisfied questions about the water yield issue in the west (Hibbert et al. 1974, Clary et al. 1974, Brown et al. 1974, Leaf 1975). Of note, is the work done at Fraser on measurement and monitoring in the 40s and to a lesser extent in the 50s, 60s, and 70s. Some of the techniques of water measurement developed at Fraser have been used as the basis for some of today's measurement and monitoring approaches (Wilm 1943, Goodell 1951, Leaf and Kovner 1970, Leaf and Kovner 1971).

Work from Fraser has demonstrated that cutting patterns affect streamflow in both quantity and timing of delivery. The work over the last 50 years has led to some of the most applied research emanating from experimental forests. The initial studies focused on hydrologic processes that affect water response (Bertle and Dunford 1950, Goodell 1948, Hoover 1962, Hoover and Leaf 1967). All of this process research on water yield and timing culminated in hydrologic computer models that synthesized work at Fraser (Leaf and Brink 1973, Leaf and Brink 1975). These models have enabled managers to easily ask "what if" questions and be provided answers -- a most valuable tool for management application of research results. A final extension of the work done at Fraser was made by Troendle and Leaf in Chapter III, Hydrology of the WRENSS Handbook (USDA Forest Service 1980). This procedural handbook has served as a principal tool for hydrologic analysis in Forest Planning and in design of best management practices for control of nonpoint pollution.

Of concern, however, is that watershed research derived from Fraser has been declining over the last decade. This is, perhaps, in part due to a shift in multiresource research, but also due to a deemphasis on watershed research. A question then arises, has Fraser fulfilled its watershed research purposes and few opportunities exist, or have we not refocused research on Fraser to today's watershed condition issues?

Let's now come back to our general charge of maintaining favorable conditions of flow. Has research helped to better define favorable conditions of flow and watershed condition, or have we been, like Alice, wandering down a path to get somewhere not sure where we have gotten? I think it can be said that the issues of the 30s, 40s, and 50s dealing with flood flows and water yield have been adequately addressed by research. The research done at Fraser and elsewhere has helped management better understand the processes affecting these components of watershed condition, and this research has been translated into better on-the-ground watershed management. Unlike Alice, we did care where we were going and took a deliberate path. However, we may be at a fork in the road, and again need to ask "which way we ought to walk from here."

Future Watershed Research Opportunities and Challenges

With the environmental awareness of the 1970s and the increasing populations in the West, came water quality legislation and demands for water uses that form the watershed issues of the 80s and 90s. The watershed issues of the future focus around (1) instream water uses and needs and their conflict with demands for water diversions, and (2) improving or maintaining water quality while meeting increasing resource demands of the land. Issues such as minimum stream flows for fisheries, instream flows for wilderness and riparian communities, flushing flows, and channel maintenance flows form the water yield and timing research needs for the coming decades. Approaches to control and management of nonpoint sources of pollution including monitoring techniques, water quality standards, and BMP design form the water quality research needs.

Research results on water yield and snowpack dynamics appear sufficient to answer management needs, and the marginal benefits to be gained from continuing this research do not warrant the investment, especially given the critical needs in the other areas of water quality and instream flows.

Water Quality Research Needs

If the current reliance on BMPs as the mechanism to control nonpoint pollution is to be successful, research information has to underpin this strategy. But before focusing on these research needs, let me first state the strategy -- or for Alice's sake, identify the destination. The key to nonpoint pollution control is through application of preventative practices (BMPs) rather than a strict reliance on instream numeric water quality standards.

The Forest Service has developed a management strategy that is compatible with the Clean Water Act and resolves the dilemma of using numeric water quality criteria as a performance standard. The primary strategy for control of nonpoint sources should be based upon design and implementation of preventive practices determined necessary for the protection of identified uses. Surveillance should be based on ensuring implementation of acceptable best management practices. The objective of BMP design should be that their implementation is the most practical means of attaining water quality goals. Water quality goals include water quality standards that adequately reflect the needs of identified beneficial uses.

It is important that implementation of land management practices developed to meet water quality objectives, and agreed to by regulatory agencies and land managers as "Best Management Practices," be sufficient to meet legal responsibilities of land managers. In an appropriate BMP/water qual-

ity standard relationship, the standards serve as a basis for measuring accomplishment of protection to the "extent feasible" and "maximum extent practicable." It is inappropriate for nonattainment of a water quality standard to be grounds for enforcement action where the agreed on BMPs were implemented. Nonattainment should be grounds for reassessing the effectiveness of BMPs and nonpoint source programs in meeting water quality goals. Monitoring results should be used for improving practices where a higher level of protection is feasible, and/or modifying water quality standards when standards are found to be unrealistic. Water quality standards are not replaced by BMPs in this strategy. Water quality standards serve as a means of evaluating program success and determining needs for change in this program, rather than in direct program enforcement. If we use the concept presented here of BMP design, monitoring, feedback of information, and adjustment of BMPs and/or water quality standards, we can and should expect that specified BMPs will meet water quality standards with time.

The strategy as presented does not presume that all responsibility for protection of the environment is automatically taken care of by compliance with designated BMPs. If environmental harm is found following application, then mitigation measures must be considered and their application negotiated. The important point is that application of agreed-to practices constitutes compliance with requirements of the Clean Water Act.

The Forest Service nonpoint source management system consists of: (1) design of site-specific BMPs based on technical, economic, and institutional feasibility, (2) application of BMPs based on scheduling, intensity, placement, and maintenance, (3) monitoring to ensure that practices are correctly designed and applied, (4) monitoring to determine effectiveness of practices in meeting water quality objectives, the appropriateness of water quality criteria for describing the needs of water dependent resources, and (5) a mechanism to adjust BMPs and/or standards as appropriate.

Research has an important role in underpinning this strategy by (1) providing information for the design and implementation requirements of BMPs, (2) providing monitoring techniques and designs that are cost-effective yet provide meaningful results, and (3) developing water quality standards that better tie to the beneficial uses and do not have the stochastic variability of water quality criteria currently being used.

Water quality standards as used in this discussion need to be defined in order to clarify the concepts presented here. Water quality standards are made up of an identification of beneficial uses, an identification of water quality criteria necessary to support those uses, and an antidegradation policy statement on how water is going to be maintained or improved. It is important to consider problems and needs as related to the three component parts of water quality standards. When reviewing existing State water quality standards, it becomes readily apparent that many criteria do not adequately represent the needs of beneficial uses. Existing water quality standards were primarily developed during the early to mid 1960's to address point sources of pollution,and tend to be discrete values. To adequately reflect the variability of the natural system, water quality standards need to be adjusted to include a stochastic expression.

The relationship between many beneficial uses and water quality criteria is not well understood, particularly in light of the natural variability discussed above. Directly related to this is a lack of understanding of the relationship between land management practices and water quality impacts. Until land use practices are better linked with water quality responses, it is difficult to define a water quality standard that is truly meaningful in nonpoint source control.

The concept of antidegradation causes concern because there are numerous ideas as to what is meant by the term. The term is not found in the Clean Water Act,but has its origin through EPA interpretation of the goals as stated in the Act. Some interpret antidegradation to mean no change at any point at any time. Such an interpretation would preclude any and all land management activities. A more reasonable interpretation would include both a temporal and spatial component. In my view, this is the only way in which natural resources can be managed in a multiple use context.

Time and space considerations of antidegradation raise another concern facing the Forest Service. How can the concern for cumulative effect be dealt with in both a planning context, and in measurement or monitoring? Forest planning and environmental analysis associated with planning and project design must consider cumulative impacts. Research and technical development of evaluation techniques are needed to discharge agency responsibilities.

Research can also help develop the water quality models that will undoubtedly be needed for the proper design of BMPs and projecting BMP effectiveness.

Instream Flow Research Needs.

Determining the instream flows necessary to support water-dependent resources is critical to many land management decisions. Management needs such information during water rights adjudications and in establishing special use permit conditions. A method has been developed for estimating the amount of flow in quantity and timing necessary to maintain channel conditions. Unfortunately, this has been developed for only one physiographic region. In addition to the need for expanding this method to other areas, there is no method for determining the amount of water needed for recreational use, esthetics, and wilderness. This will be a critical need in the very near future, particularly in the Western States where water is in short supply. These are not easy questions. If water is needed in a babbling brook or a water fall, how much is needed? If water is needed to maintain the wilderness character, how much is needed? If some water can be removed, how can an estimate be made? It is important that rational methods

which are technically defensible be developed for these flow determinations.

In most cases, courts have not ruled against agency decisions if those decisions were arrived at using procedures and methods that produce consistent results. A problems arises when decisions are shown to be arbitrary and capricious. The best defense is to have defensible methods upon which to base decisions and to clearly display these efforts to the public. Whether we like it or not as resource managers, we operate in a glass house and must justify our actions.

Hydrologic Models And Research Needs

For the forest land manager, existence and use of models have been both a benefit and a curse. As a benefit, models have provided valuable insight for making land management decisions. As a curse, models have been used inappropriately by regulators who choose not to recognize model limitations in land use control decisions. A problem lies in how models and model use are viewed by the specialist or researcher, and how they are viewed by a regulator. Models as used in research are generally constructed to better understand how a "system" operates. Cause-effect relationships are established between land use activities and hydrologic parameters to match the natural system. The match is established through repeated refinement of parameters and interrelationships among parameters based on runs of known data sets. Once a good correlation is established between what actually occurs as based on the data set and model prediction, then parameters can be varied and results evaluated based on model output. This process allows for study of the "system;" hopefully, providing insight into how natural processes work. Even in this use of models, it is dangerous to place too much reliance on absolute values obtained. How well models approximate the real world is dependent on our interpretation of cause-effect relationships: the more empirical the relationships used the more questionable the results.

Thus far in this discussion of model use, no attempt has been made to apply the model to a situation outside data sets. When models are applied outside data sets, reliance on generated information must be viewed carefully. Specialists have often used model extrapolation to make estimates of the impact for proposed land management practices. Such results cannot be used as absolutes, however, and must be used as indicators only so that informed decisions can be made based upon risk. Unfortunately, in some cases in our attempts to get "the job done," specialists and line officers have used model outputs as accurate representations of reality, rather than as only one piece of information with appropriate recognition of limitations. In some cases, for example, we have displayed comparisons between management alternatives based on model estimates that indicate small differences, when in fact the differences between alternatives are much less than the statistical reliability of the models.

In quests for a means to estimate effects of land uses in advance of activities, regulators have often used, or proposed to use, models to estimate impacts and to control land use. While it would be desirable to predict such impacts in advance, it is not possible to do so at a level of accuracy and precision sufficient for regulatory control.

It is important for research to continue development of better and more accurate cause-effect models and to accommodate stochastic inputs for evaluation of risk based on climatic variability. It is incumbent on the technical community to ensure that models are not misused by land managers and regulatory agencies. Using a model just because it is the "best we have" is not good enough. If it does not answer the questions posed it should not be used.

The Fraser Experimental Forest can contribute to investigation of both the instream needs as well as the water quality needs.

Conclusions

Research has provided useful information to help management better understand what has come to be broadly defined as watershed condition. However, the research questions asked today are far more complex than in the past. To answer these questions, research can no longer rely on an individual scientist or singe experimental forest. Integrated research must be employed. This integration will involve a team approach using hydrologists, soil scientists, geologists, fisheries biologists, foresters, and other disciplines. This research will also necessitate integration of research results from many experimental watersheds. The Fraser Experimental Forest can contribute to investigation of both the instream needs as well as the water quality needs.

I challenge research to undertake these research opportunities discussed today in ways much different from the past. The use of team research may be somewhat new for many scientists, but it is a necessity if we are to gain answers to the complex issues of today. I also challenge research to keep a focus on the overall objective, "favorable conditions of flow," as research projects are contemplated. Each watershed research project should fit within this overall objective.

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Big Game Habitat Research in Subalpine Forests in the Central Rocky Mountains

Glenn L. Crouch[1]

Abstract.--Research findings indicate that subalpine forests similar to those on the Fraser Experimental Forest provide growing season habitat for deer and elk, but are unsuitable as winter range because of deep snow. Even in the growing season, their value as forage producers may be limited by closed canopies. Segments of these forests apparently can also provide year-round habitat for moose.

The Fraser Experimental Forest is a high elevation (8,800 to 12,800 feet), north-facing alpine and subalpine tract of about 23,000 acres in north-central Colorado. About one-third of the total acreage is above timberline and the remainder is tightly forested, with few natural openings (Alexander et al. 1985). This paper is concerned with the subalpine portion of the Experimental Forest.

Rocky Mountain elk *(Cervus elaphus nelsoni)* and mule deer *(Odocoileus hemionus hemionus)* are the major big game species that seasonally utilize the alpine and subalpine communities on the Fraser Forest. The Forest serves as summer range for nominal, but huntable, populations of elk and deer (fig. 1). Both are absent when deep snow hinders their movement and covers the low-growing understory vegetation that is virtually the only nonconifer food source available in winter. The wintering areas of Fraser elk and deer have not been identified, but probably are north and west of the Experimental Forest on the eastern edge of the well-known Middle Park winter range (Gilbert et al. 1970, Carpenter et al. 1979; Tiedeman et al. 1987) (fig. 2).

Black bear *(Ursus americanus)* are occasional visitors, and moose *(Alces alces shirasi)* may have become resident on the Forest since their reintroduction into Colorado in 1978 and 1979 (Nowlin 1985).[2]

The newest big game animal on Fraser also is the largest. In 1978, moose were released into Colorado, near the town of Rand, about 40 miles north of the Experimental Forest (Nowlin 1985). During their first year, at least one moose traveled almost half the distance from the release site to the Fraser Forest. By 1982, moose were infrequently observed on the Forest, and soon afterward a year-round population apparently was established. These moose move extensively through the year, but their major habitat appears to be willow-dominated areas adjacent to the lower reaches of the larger streams on, and adjacent to, the Experimental Forest (fig. 3). Although numbers of moose are not known, they are regularly seen by workers on Fraser.

VEGETATION

Vegetation on the Forest has not been classified or mapped, but the *Abies lasiocarpa/Vaccinium scoparium* habitat type is dominant, and *V. scoparium* is the major understory species below timberline (Wallmo et al. 1972, Crouch 1985, Hess and Alexander 1986).

Other habitat types present in the *A. lasiocarpa* series include *A. lasiocarpa/Senecio triangularis* and *A. lasiocarpa/Calamagrostis canadensis*. Both produce much understory vegetation, but are limited to moist sites and occur sparingly on most of the Forest. *A. lasiocarpa/Carex geyeri* is present; but its acreage also appears to be limited.

Additional habitat types or plant communities identified include *Pinus contorta/V. scoparium, P. contorta/Shepherdia canadensis*, and *P. contorta/Carex geyeri*. Acreages of these are relatively small.

Infrequent, but potentially important, communities include a few unclassified, nearly pure stands of *Populus tremuloides*, mid-height *Salix* spp.-dominated communities along water courses, a single stand of *Artemisia* sp., and minor acreages of multispecies grass-forb stringer meadows. Also present, at lower elevations that burned during logging early in the century, is a 900-acre *P. contorta*-dominated stand that contains various proportions of *P. tremuloides*.

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[2] Personal communication, Colorado Division of Wildlife, April 1987.

BIG GAME HABITAT RESEARCH

With few exceptions, habitat studies have been evaluations of the experimental application of various timber management practices that are designed to enhance water production for downstream users.

Completed Studies

Fool Creek

Research on big game habitat on the Experimental Forest began in the late 1950s after timber was harvested on the Fool Creek study area (figs. 4 and 5). There, during 1954-56, 278 acres of mature timber on 550 acres of commercial forest land were clearcut in alternate, variable width strips, to increase streamflow (Alexander et al. 1985). Two years after logging, more mule deer fecal groups were found on clearcut than on uncut strips, and production of some plant species was somewhat greater on the clearcut areas (Porter 1959). Fecal counts in 1966, about 10 years later, showed nearly three times more deer droppings per acre on clearcut than on uncut strips (Wallmo 1969).

Figure 1.--Elk in an aspen opening in central Colorado.

Figure 2.--Middle Park; probable winter range for deer and elk from the Fraser Experimental Forest.

Figure 3.--Moose tracks in winter on the Fraser Experimental Forest.

Deer feeding preferences and amounts of forage available to them in the snow-free season were studied in 1970 and 1975, 15 to 20 years after logging. Results showed that deer fecal counts and forage production were still greater on clearcut than on uncut strips, but that inherent forage quality as indexed by crude protein content and digestibility was not different between the two treatments (Wallmo et al. 1972, Regelin et al. 1974, Regelin and Wallmo 1978).

Deadhorse Creek

Crouch (1985) monitored vegetation response to a different timber harvest pattern. This study, conducted on a south-facing segment of the 667-acre Deadhorse Creek watershed, involved a state-of-the-art cutting practice for maximizing water production (fig. 6). Here, 12 more or less evenly spaced, 3-acre circular patches were clearcut in a 101-acre segment of the watershed (Troendle 1983). The Deadhorse site was similar to that on the Fool Creek study area, but

understories generally were drier and less productive (Wallmo et al. 1972, Crouch 1985).

Data were collected over 5 years in five of the twelve 3-acre plots to be clearcut, and five uncut controls (figs. 7 and 8). All of the control and four of the blocks to be clearcut were *A. lasiocarpa/V. scoparium* habitat types. The remaining harvest block was a much more mesic *A. lasiocarpa/Senecio triangularis* habitat type. By the fifth growing season, plant production was unchanged on the uncut blocks; but had increased from 225 to 673 pounds per acre on the average blocks, and from 622 to 3,295 pounds per acre on the moist block (fig. 9).

Crude protein content was unchanged on uncut plots, but increased on the average clearcuts after logging.

Over the 5-year evaluation, there were no differences in numbers of elk fecal groups before and after clearcutting, although numbers increased gradually on the average clearcut sites. Numbers of deer droppings, however, increased over the postlogging period on all blocks. Elk and deer droppings were both more abundant after clearcutting on the mesic site.

The major response of understory production and herbivore activity on the mesic *A. lasiocarpa/Senecio triangularis*

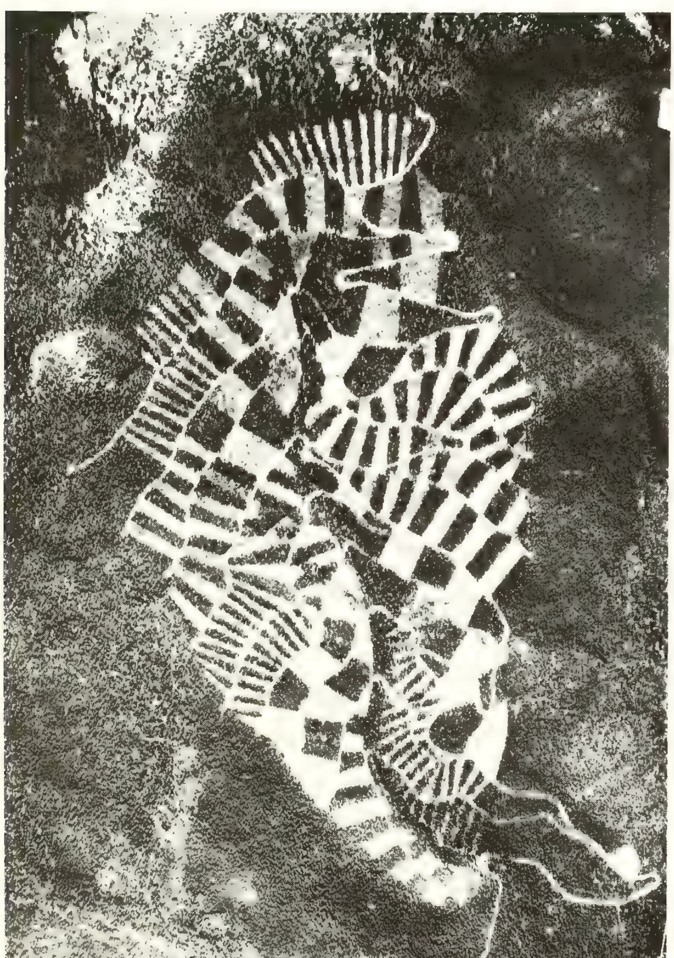

Figure 4.--Fool Creek watershed in 1957.

Figure 5.--Fool Creek watershed in 1985.

Figure 6.--Three-acre circular clearcuts designed to augment streamflow on the Deadhorse Creek watershed.

Figure 7.--Clearcut block in subalpine timber 2 years after logging on the Deadhorse Creek watershed.

Figure 8.--Clearcut block shown in figure 7 in the ninth winter after logging.

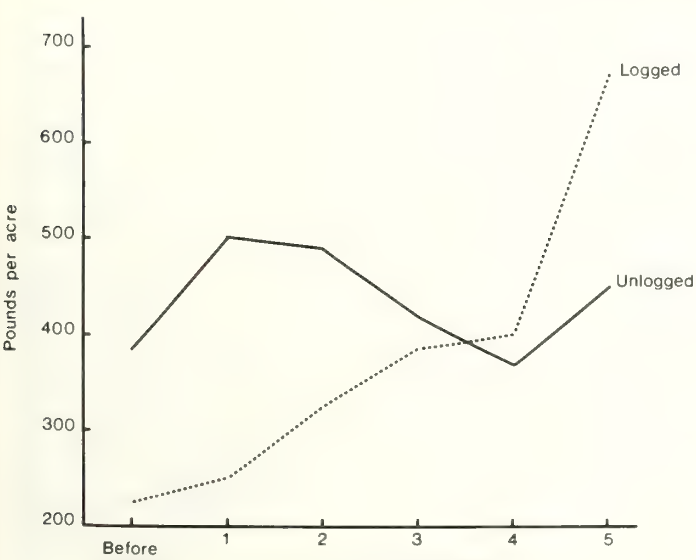

Figure 9.--Dry weight understory plant production (pounds per acre) on uncut and clearcut blocks, Deadhorse Creek watershed.

Figure 10.--Growing stock level (GSL) 40, 8 years after thinning in <u>Pinus contorta</u>, Fraser Experimental Forest.

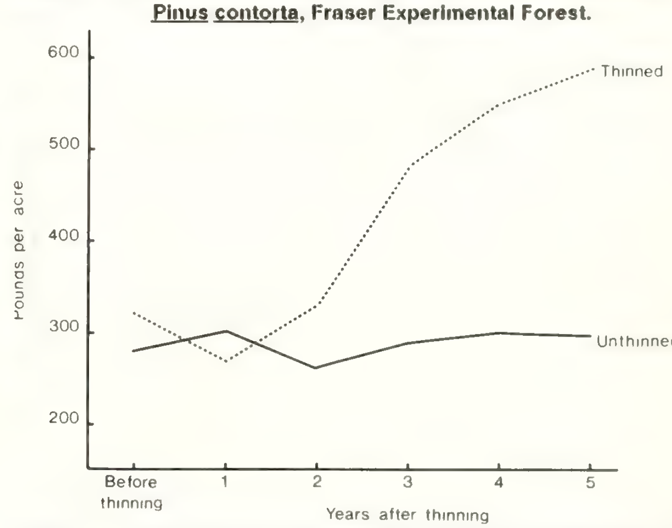

Figure 11.--Dry weight understory plant production (pounds per acre) before and after thinning to growing stock level (GSL) 40 in pole-sized <u>Pinus contorta</u>.

block suggests that these sites may be prime candidates for forage enhancement treatments.

<u>Pinus contorta</u> Stocking Control

Plant production and related understory components were monitored before and after treatments to control growing stock levels (GSLs) in 60-year-old *P. contorta* growing at the lowest elevations on the Experimental Forest (Crouch 1986) (figs. 10 and 11). Vegetation on most of the area resembled *P. contorta/V. scoparium* and *P. contorta/Carex geyeri* plant communities as described by Hess and Alexander (1986).

Plant production, cover, crude protein content, and digestibility all increased over 5 years at the lower GSLs 40 and 80, and were essentially unchanged on controls and GSL 120 plots.

According to numbers of fecal groups, deer and cattle preferred the more heavily thinned blocks, but elk exhibited no preference among GSL categories.

Figure 12.--Shelterwood harvest in subalpine timber in central Colorado.

Figure 14.--Fence line in a Populus tremuloides clearcut shows effects of browsing by deer, elk, and cattle.

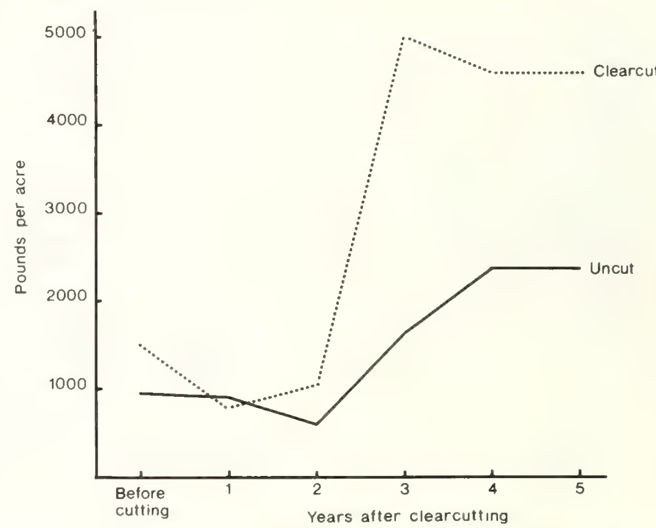

Figure 15.--Dry weight understory plant production before and after clearcutting in a stand of Populus tremuloides.

Ongoing Fraser Studies

Current studies consist mainly of continued monitoring of effects of the following treatments on vegetative components and big game activity.

1. Small-block clearcutting in mature *A. lasiocarpa/V. scoparium* and *A. lasiocarpa/Senecio triangularis* habitat types.
2. The first entry of a three-step shelterwood harvest in mature *A. lasiocarpa/V. scoparium* habitat types (figs. 12 and 13).
3. Clearcutting in mature *P. contorta/V. scoparium* and *P. contorta/Shepherdia canadensis* habitat types.
4. Clearcutting and partial cutting in a single stand of pole-sized *Populus tremuloides* (figs. 14 and 15).

Other Ongoing Studies

Forest Service big game habitat research elsewhere in the subalpine forests in the central Rocky Mountains is being conducted in aspen stands at five locations in western Colorado (fig. 16). On these sites, effects of aspen regeneration practices, including commercial clearcutting, on vegetative components and big game activity are being investigated.

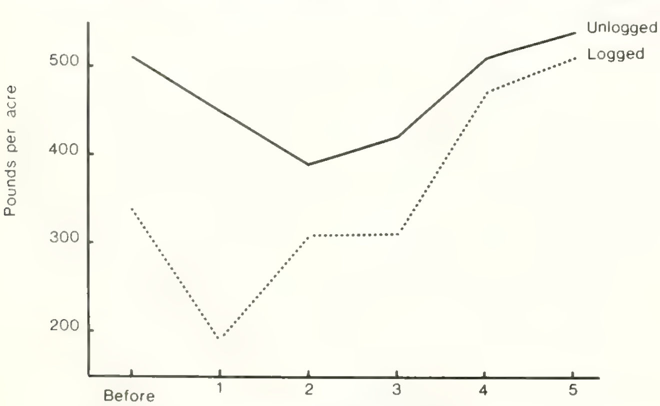

Figure 13.--Dry weight understory plant production before and after shelterwood harvesting.

Related Previous Research

Earlier research on deer and elk feeding and use of subalpine habitats has been conducted elsewhere in the central Rocky Mountains. Nichols (1957), Harris (1958), and Boyd (1970) studied elk on summer and winter ranges on the White River Plateau, about 75 miles west of the Fraser Forest. More recently, elk and deer diets and habitat use were studied intensively in subalpine habitats in northern Utah, about 300 miles northwest of the Fraser Forest (Collins et al. 1978; Deschamps et al. 1979; Collins and Urness 1979, 1983).

One hundred miles north of the Experimental Forest in the subalpine forests of southern Wyoming, a series of studies determined effects of road building, logging, cattle grazing,

and other disturbance factors on elk and their habitats (Ward 1973, 1976; Ward et al. 1973).

Finally, Hobbs and others, working in nearby Rocky Mountain National Park, determined the composition and quality of elk winter and summer ranges (Baker and Hobbs 1982, Hobbs et al. 1981). Also estimated were elk winter range carrying capacities based on energy and nitrogen characteristics of the diets (Hobbs et al. 1982).

SUMMARY

Subalpine forests similar to those at Fraser provide growing-season habitat for deer and elk but are unsuitable as winter range, primarily because of deep snow and secondarily because they lack tall- and mid-height shrub understories. Their value as growing-season habitat also may be limited by the closed-canopy stands that dominate these ecosystems unless opened by fire or management activities.

However, as elsewhere, the critical factor regarding improvement of the capability of subalpine forests to support more deer and elk is the inability of their off-site winter ranges to support more animals, especially during severe winters, such as those that periodically occur in the central Rockies. Segments of these forests apparently can also provide year-round habitat for moose, although the permanence of the population at Fraser has not yet been established.

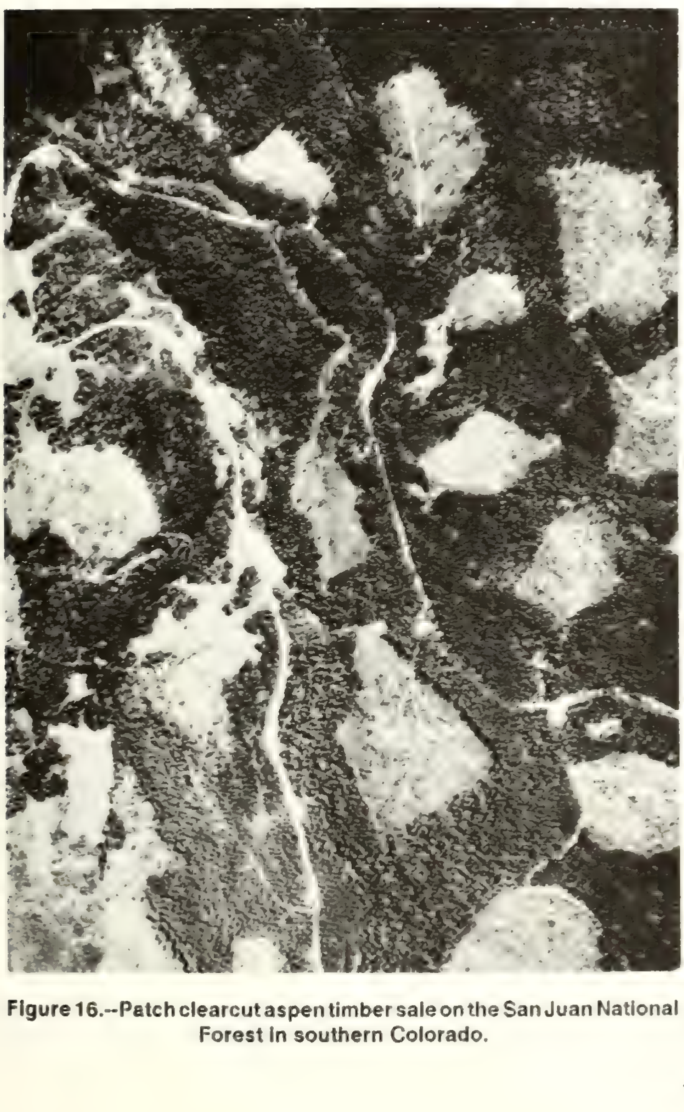

Figure 16.--Patch clearcut aspen timber sale on the San Juan National Forest in southern Colorado.

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Nongame Wildlife Research in Subalpine Forests of the Central Rocky Mountains

Martin G. Raphael[1]

Abstract--Subalpine forests of the central Rocky Mountains provide habitat for 145 species of amphibians, reptiles, birds, and mammals. Perhaps because of extreme seasonal climate and the relatively simple structure and composition of subalpine forest, diversity of wildlife is lowest of any forest type in the region. No species are found only in subalpine habitats but some, e.g., southern red-backed vole, reach their maximum abundance there. Research to date has emphasized community structure; much additional work is needed to understand population dynamics and habitat relationships of species that find optimum habitat conditions in subalpine forests.

Subalpine forests of Engelmann spruce, subalpine fir, and lodgepole pine cover about 5 million ha of forest land in Colorado and Wyoming and account for over 90% of sawtimber volume (USDA Forest Service 1980). The climate of the subalpine zone is harsh. Subalpine forests occur at elevations ranging from about 2,700 to 3,600 m where the mean annual temperature is about 2°C. Annual temperature variation is extreme, ranging from -45°C to over 30°C. Annual precipitation varies from 50 to 90 cm, falling primarily as snow from October through May. The frost-free period is very short, usually less than 60 days.

As a result of these harsh conditions, subalpine forests are rather simple in composition and annual productivity is low. Engelmann spruce and subalpine fir are usually codominant although one species may dominate in some stands. At lower elevations and on drier sites, lodgepole pine is often associated with spruce and fir and, on southerly slopes, sometimes occurs in pure stands. Understory cover is usually sparse, consisting primarily of common juniper and grouse whortleberry.

The purposes of this report are to (1) summarize field studies of the occurrence of nongame wildlife species in subalpine forests, (2) compare the fauna of subalpine to other Rocky Mountain forest habitats, (3) compare the fauna of the Rocky Mountains with that of coniferous forests in other regions in North America, (4) briefly summarize the status of our knowledge of habitat associations of subalpine wildlife, and (5) to summarize results of studies documenting the responses of these species to habitat disturbance caused by fire and logging.

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THE SUBALPINE VERTEBRATE COMMUNITY

Diversity of wildlife in subalpine forests is the lowest among habitat types in the central Rocky Mountain region (fig. 1). Hoover and Wills (1984) list 5 amphibian species, no reptiles, 38 mammals, and 76 birds that occur in subalpine forest of Colorado. If lodgepole pine (which is considered a separate habitat type by Hoover and Wills) is included within subalpine, a total of 5 amphibian, 2 reptile, 93 bird, and 45 mammal species occur in the combined habitat types in Colorado (fig. 2). The Wyoming Wildlife Database (Anderson and Patterson 1983) includes 2 amphibians, 4 reptile, 83 bird, and 52 mammal species that occur in subalpine forest of Wyoming.

Not only is the diversity of vertebrates low in subalpine forest compared to other habitat types in the Rocky Mountain region, vertebrate diversity in coniferous forests of the Rockies is low compared to other North American regions. When Wiens (1975) compared numbers of bird species reported in censuses conducted in Rocky Mountain conifer habitats to averages in the northeast, southeast, northern, Sierra Nevada, and northwest coastal forests, he found that Rocky Mountain forests supported an average of 14.0 bird species compared to 14.5-22.6 species in the other regions.

Most of the vertebrate species listed for subalpine habitats also occur in other forest habitats (figure 2, after Hoover and Wills 1984: Appendix A). For example, if one compares the list of species in subalpine habitat to lodgepole pine (fig. 2), most of the species for the combined habitats occur in both. A lesser number occur in lodgepole but not subalpine, and still fewer occur in subalpine but not in lodgepole. Among reptiles and amphibians, species overlap between subalpine and other

habitats (number of species occurring in both habitats divided by the total species occurring in the two habitats) was greatest with aspen and high elevation riparian habitats (71% each) and lowest with ponderosa pine (22%). For both birds and mammals, overlap was greatest with lodgepole pine (76% for each group) and, as was the case for reptiles and amphibians, lowest for ponderosa pine (53% for birds, 44% for mammals). Thus, few species occurring in subalpine habitat are unique to that type.

The overall similarity of wildlife species (percentage of species shared) among Rocky Mountain habitats is shown in figure 3. Subalpine and high elevation riparian habitats are most similar for reptiles and amphibians, followed by aspen, Douglas-fir, and lodgepole pine. These habitats form one related group that is only slightly similar (20%) to the remaining habitats. The overall clustering of habitats for birds and

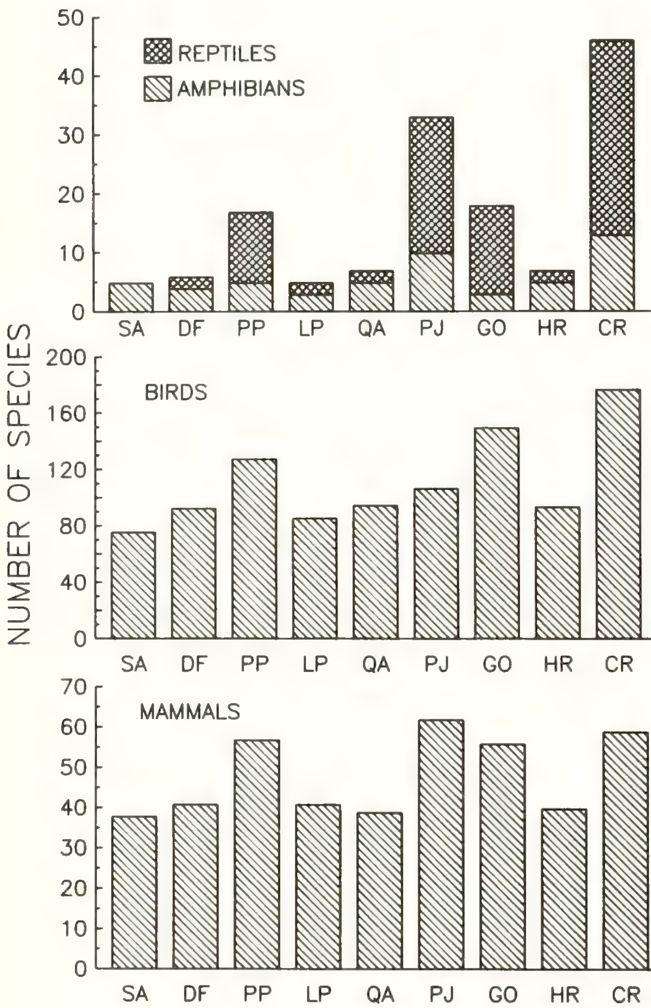

Figure 1.--Number of species of reptiles, amphibians, birds, and mammals in Colorado habitats (SA = subalpine, DF = Douglas-fir, PP = ponderosa pine, LP = lodgepole pine, QA = quaking aspen, PJ = pinyon juniper, GO = Gambel oak, HR = high elevation riparian, CR = cottonwood riparian). Data from Hoover and Wills (1984).

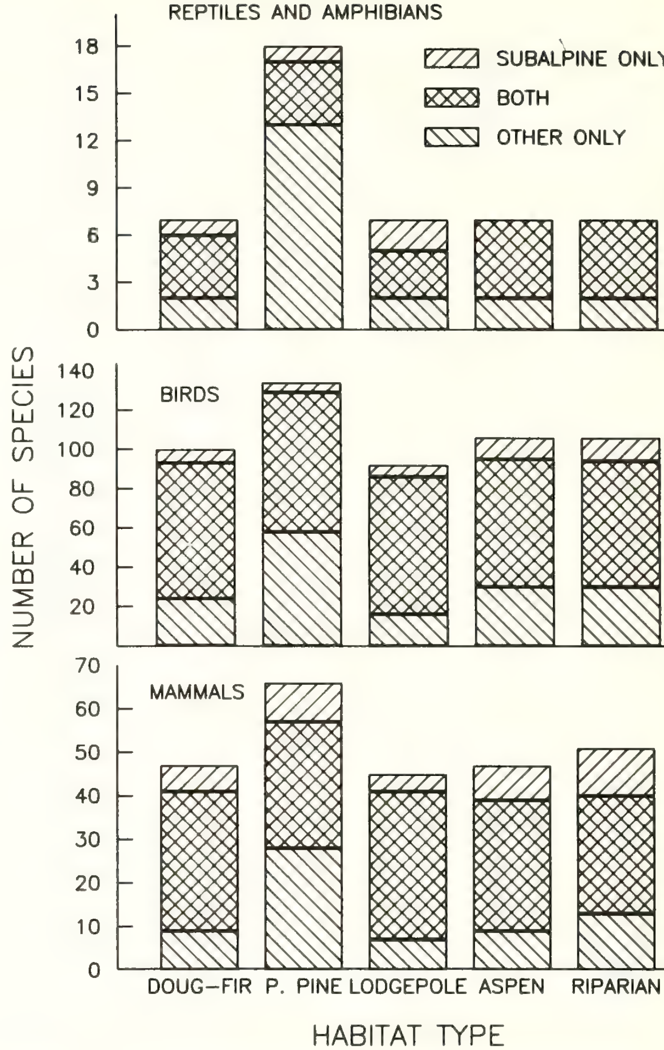

Figure 2.--Comparisons of species composition of subalpine forest with other forest types in Colorado (crosshatching indicates the number of species in common between subalpine and each other habitat type).

mammals follow a similar pattern, except that ponderosa pine is included with the subalpine group for birds. These cluster analyses show that wildlife species are fairly similar between the high elevation conifer, aspen, and riparian habitats and are similar between a lower elevation juniper, oak and cottonwood habitats but that the two groups of habitats share few species.

To better characterize the bird community associated with subalpine habitats, I reviewed all available published census data for the central Rocky Mountain region. This review yielded 19 studies which report occurrence of birds from a total of 54 sites described as subalpine forest. These studies reported 75 bird species, almost half of which were rare, occurring on fewer than 10 percent of the sites (table 1). Fourteen species occurred on 50 percent or more of the sites (table 2). Because these species are widespread among the sites included in this survey, they may be considered most typical of subalpine forest. It is interesting to note that most of

these species are also distributed throughout coniferous forests of North America (table 2). The most narrowly distributed species among those listed are mountain chickadee and Cassin's finch, which occur only in the Sierra Nevada in addition to the Rocky Mountains.

Most of these abundant species feed on insects or seeds in canopy foliage; lesser numbers forage on the ground or are timber drilling or searching. Wiens (1975) compared the distribution of birds among regions based on their foraging position (foliage, ground, timber, air) and found that foliage-feeding species dominated in all North American coniferous forests. Rocky Mountain birds, however, had the highest

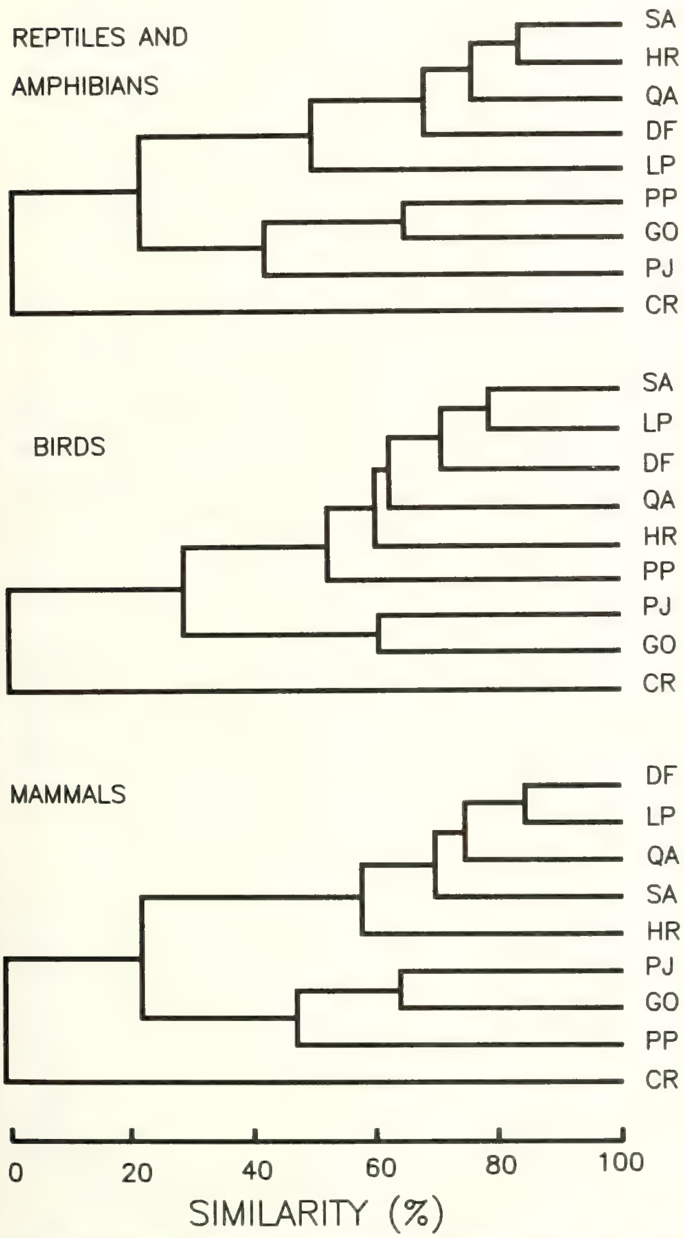

Figure 3.--Overall similarity (percentage of species shared) among Colorado habitat types (see figure 1 for abbreviations). Vertical lines joining groups indicate percent similarity of numbers of the group.

Table 1.--Frequency of occurrence (%) of bird species recorded during census of 54 subalpine forest plots in the central Rocky Mountains.[1]

Species	Percent occurrence among 54 sites
Northern Harrier *(Circus cyaneus)*	2
Sharp-shinned Hawk *(Accipiter striatus)*	6
Cooper's Hawk *(Accipiter cooperii)*	9
Northern Goshhawk *(Accipiter gentilis)*	9
Red-tailed Hawk *(Buteo jamaicensis)*	6
Golden Eagle *(Aquila chrysaetos)*	7
American Kestrel *(Falco sparverius)*	4
Merlin *(Falco columbarius)*	4
Blue Grouse *(Dendragapus obscurus)*	11
Ruffed Grouse *(Bonasa umbellus)*	7
Mourning Dove *(Zenaida macroura)*	20
Great Horned Owl *(Bubo virginianus)*	24
Northern Pygmy-Owl *(Glaucidium gnoma)*	4
Boreal Owl *(Aegolius funereus)*	2
Northern Saw-whet Owl *(Aegolius acadicus)*	2
Common Nighthawk *(Chordeiles minor)*	4
Broad-tailed Hummingbird *(Selasphorus platycercus)*	33
Yellow-bellied Sapsucker *(Sphyrapicus varius)*	19
Williamson's Sapsucker *(Sphyrapicus thyroideus)*	30
Downy Woodpecker *(Picoides pubescens)*	7
Hairy Woodpecker *(Picoides villosus)*	50
Three-toed Woodpecker *(Picoides tridactylus)*	14
Black-backed Woodpecker *(Picoides arcticus)*	4
Northern Flicker *(Colaptes auratus)*	44
Olive-sided Flycatcher *(Contopus borealis)*	30
Western Wood-Pewee *(Contopus sordidulus)*	26
Empidonax spp. *(hammondi* or *oblerholseri)*	35
Western Flycatcher *(Empidonax difficilis)*	20
Purple Martin *(Progne subis)*	6
Tree Swallow *(Tachycineta bicolor)*	20
Gray Jay *(Perisoreus canadensis)*	56
Steller's Jay *(Cyanocitta stelleri)*	15
Clark's Nutcracker *(Nucifraga columbiana)*	39
Black-billed Magpie *(Pica pica)*	6
American Crow *(Corvus brachyrhyncos)*	6
Common Raven *(Corvus corax)*	6
Black-capped Chickadee *(Parus atricapillus)*	19
Mountain Chickadee *(Parus gambeli)*	93
Red-breasted Nuthatch *(Sitta canadensis)*	65
White-breasted Nuthatch *(Sitta carolinensis)*	6
Brown Creeper *(Certhia americana)*	46
Rock Wren *(Salpinctes obsoletus)*	4
House Wren *(Troglodytes aedon)*	19
American Dipper *(Cinclus mexicanus)*	2
Golden-crowned Kinglet *(Regulus satrapa)*	54
Rudy-crowned Kinglet *(Regulus calendula)*	81
Mountain Bluebird *(Sialia currucoides)*	13

(continued)

Table 1.--(continued).

Species	Percent occurrence among 54 sites
Townsend's Solitaire *(Myadestes townsendi)*	30
Swainson's Thrush *(Catharus ustulatus)*	31
Hermit Thrush *(Catharua guttatus)*	74
American Robin *(Turdus migratorius)*	83
Cedar Waxwing *(Bombycilla cedrorum)*	2
Warbling Vireo *(Vireo gilvus)*	24
Yellow Warbler *(Dendroica petechia)*	6
Yellow-rumped Warbler *(Dendroica coronata)*	91
Ovenbird *(Seiurus aurocapillus)*	2
MacGillivray's Warbler *(Oporornis tolmiei)*	9
Wilson's Warbler *(Wilsonia pusilla)*	6
Western Tanager *(Piranga ludoviciana)*	46
Black-headed Grosbeak *(Pheucticus melanocephalus)*	6
Lazuli Bunting *(Passerina amoena)*	7
Green-tailed Towhee *(Pipilio chorurus)*	2
Chipping Sparrow *(Spizella passerina)*	52
Vesper Sparrow *(Pooecetes gramineus)*	2
Song Sparrow *(Melospiza melodia)*	7
Lincoln's Sparrow *(Melospiza lincolnii)*	22
White-crowned Sparrow *(Zonotrichia leucophrys)*	20
Dark-eyed Junco *(Junco hyemalis)*	96
Brown-headed Cowbird *(Molothrus ater)*	9
Pine Grosbeak *(Pinicola enucleator)*	57
Cassin's Finch *(Carpodacus cassinii)*	59
Red Crossbill *(Loxia curvirostra)*	31
White-winged Crossbill *(Loxia leucoptera)*	4
Pine Siskin *(Carduelis pinus)*	87
Evening Grosbeak *(Coccothraustes vespertinus)*	6

[1]*Sources included Snyder 1950 (2 sites), Thatcher 1956, Salt 1957 (3 sites), Webster 1967, Burr 1969, Kingery 1970, 1971, 1973, Winn 1976 (8 sites), Young 1977 (8 sites), Roppe and Hein 1978, Thompson 1978 (4 sites), Austin and Perry 1979 (2 sites), Harvey and Weaver 1979 (2 sites), Taylor and Barmore 1980 (3 sites), Smith and MacMahon 1981 (2 sites), Scott et al. 1982 (2 sites), Raphael (this symposium, 3 sites), Keller 1987 (10 sites).*

percentage (28%) of ground foraging birds and a lower percentage of foliage feeding birds (53%) compared with percentages of total density in other regions.

Total density of birds is low in Rocky Mountain coniferous forests compared with other regions (fig. 4). Wiens (1975) reported an average of 736 birds/100 ha (s.d. = 575) for all conifer habitats in the Rocky Mountain region. Among those studies reporting total density estimates (as summarized in table 1), I calculated a mean of 577 birds/100 ha (s.d. = 472, n = 31) which is lower than averages of all but the northern region (fig. 4).

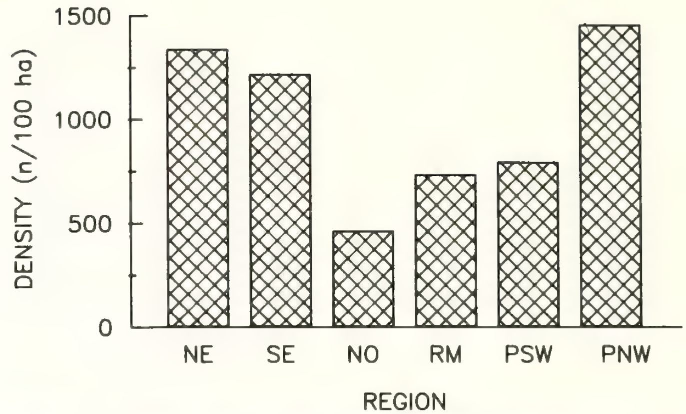

Figure 4.--Comparisons of abundance of birds among conifer forest regions in North America (NE = Northeast, SE = Southeast, NO = Northern, RM = Rocky Mountain, PSW = Pacific Southwest, PNW = Pacific Northwest), after Wiens (1975).

Biomass (total weight of all birds) averages 188 g/ha for all conifer forest types in the Rocky Mountain region (Weins 1975). For subalpine forests, I calculate a similar average of 187 g/ha based on data cited in table 1. Salt (1957) compared bird biomass in several habitat types and separated total biomass into that contributed by herbivores and carnivores (fig. 5). Biomass was much lower in subalpine forest types than in riparian, meadow, and aspen types, primarily because of the greater contribution of carnivores in the latter types. One possible explanation of this pattern is that insect biomass (primarily prey of carnivores) is greater in these habitats than in subalpine forest. In support of this argument, Schimpf and MacMahon (1985) found that insect density, diversity, and mean body size were all at least twice as great in aspen compared to subalpine forest.

Nongame mammals have received little study compared to efforts on birds. I found 11 studies enumerating small mammal faunas in subalpine forests of the Rocky Mountains (table 3). Altogether, these studies list 24 mammal species, of which only

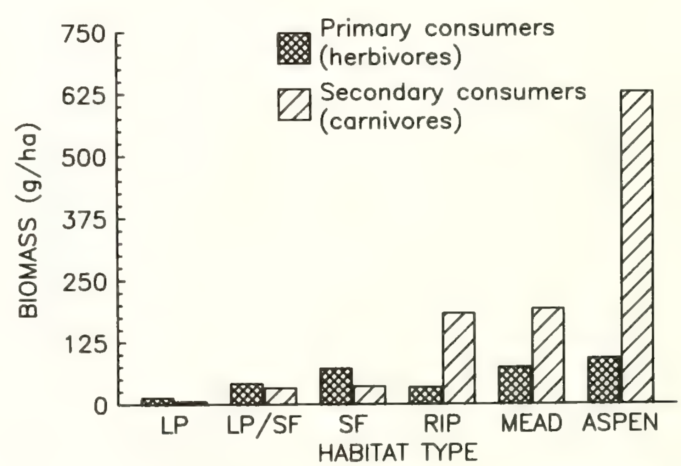

Figure 5.--Biomass of birds among habitat types in Wyoming (LP = lodgepole pine, LP/SF = lodgepole and spruce-fir, SF = spruce-fir, RIP = riparian, MEAD = meadow, after Salt (1957).

Table 2.-- The 14 most commonly reported bird species from subalpine sites (n = 54) in the central Rocky Mountains.[1]

Species	Frequency	Foraging Guild	Distribution[2] NE	SE	NO	SN	PN
Dark-eyed Junco	96	ground-seed	X	X	X	X	X
Mountain Chickadee	93	foliage-insect	X				
Yellow-rumped Warbler	91	foliage-insect	X	X	X	X	
Pine Siskin	87	foliage-seed	X	X	X	X	X
American Robin	83	ground-insect	X	X	X	X	X
Ruby-crowned Kinglet	81	foliage-insect	X	X	X	X	
Hermit Thrush	74	ground-insect	X	X	X	X	X
Red-breasted Nuthatch	65	timber-searching	X	X	X	X	X
Cassin's Finch	59	ground-seed	X				
Pine Grosbeak	57	foliage-seed	X	X	X		
Gray Jay	56	foliage-seed	X	X	X		
Golden-crowned Kinglet	54	foliage-insect	X	X	X	X	X
Chipping Sparrow	52	ground-insect	X	X	X	X	X
Hairy Woodpecker	50	timber-drilling	X	X	X	X	X

[1]*See table 1 for citations.*

[2]*NE = northeast, SE = southeast, NO = northern, SN = Sierra Nevada, PN = Pacific northwest (after Wiens 1975).*

Table 3.--Frequency of occurrence of small mammal species among 29 sites in subalpine forests of the central Rocky Mountains.[1]

Species[2]	Frequency (%)
Unidentified Shrew (*Sorex* spp.)	31
Masked Shrew *(Sorex cinereus)*	14
Dusky Shrew *(Sorex monticolus)*	14
Water Shrew *(Sorex palustris)*	7
Nuttall's Cottontail *(Syvilagus nuttalli)*	7
Snowshoe Hare *(Lepus americana)*	34
Least Chipmunk *(Tamias minimus)*	28
Colorado Chipmunk *(Tamias quadrivittatus)*	3
Red-tailed Chipmunk *(Tamias ruficaudus)*	17
Uinta Chipmunk *(Tamias umbrinus)*	45
Columbian Ground Squirrel *(Spermophilus columbianus)*	3
Golden-mantled Ground Squirrel *(Spermophilus lateralis)*	28
Red Squirrel *(Tamiasciurus hudsonicus)*	48
Northern Flying Squirrel *(Glaucomys sabrinus)*	41
Northern Pocket Gopher *(Thomomys talpoides)*	10
Deer Mouse *(Peromyscus maniculatus)*	93
Southern Red-backed Vole *(Clethrionomys gapperi)*	86
Heather Vole *(Phenacomys intermedius)*	14
Meadow Vole *(Microtus pennsylvanicus)*	3
Montane Vole *(Microtus montanus)*	21
Long-tailed Vole *(Microtus longicaudus)*	17
Western Jumping Mouse *(Zapus princeps)*	45
Porcupine *(Erithizon dorsatum)*	7
Ermine *(Mustela erminea)*	10
Long-tailed Weasel *(Mustela frennata)*	21

[1]*Williams 1955 (2 sites), Negus and Findley 1959 (2 sites), Brown 1967a,b (2 sites), Winn 1976 (8 sites), Austin and Urness 1977 (2 sites), Anderson et al. 1980 (2 sites), Ramirez and Hornocker 1981 (2 sites), Scrivner and Smith 1984 (4 sites), Palmer 1986 (2 sites), Raphael (these proceedings, 3 sites).*

[2]*Names follow Jones et al. 1982.*

2 (deer mouse and southern red-backed vole) occurred on over half of the 29 sites sampled; 17 species occurred on less than one-third of the sites. The deer mouse is distributed throughout North America in nearly every habitat, forested and nonforested. The southern red-backed vole occurs in forests of Canada, the Rocky Mountains, and the northestern states. In many of the studies listed in table 3, this species was the most abundant small mammal and seems to find subalpine forest as its optimum habitat (e.g., fig. 6).

Whereas fewer species of small mammals are sampled in subalpine forest compared with birds, biomass of mammals is much higher. Vaughan (1984) estimated biomass of mammals in subalpine meadows from 3,171 to 3,537 g/ha in a three-year study; Anderson et al. (1980) estimated values from 2,228 g/ha on a spruce site to 3,593 g/ha on a fir site. These values, though undoubtedly subject to large error due to difficulties estimating small mammal density, are an order of magnitude greater than values for birds (which averaged only 187 g/ha, and ranged from 69 to 611 g/ha). In contrast to birds, most of the biomass of small mammals (67%) is contributed by herbivorous species (Vaughan 1984).

HABITAT ASSOCIATIONS

General Relationships

Compared to forests in other regions in North America, subalpine forests of the central Rocky Mountain area have received little study regarding habitat relationships of nongame wildlife. Hoover and Wills (1984) summarize general principles and report abundance of management indicator species in seral stages of major forest habitat types (ecosystems) in Colorado. Similar tabulations are available for Wyoming (Bernard and Brown 1978, Findholt et al. 1981,

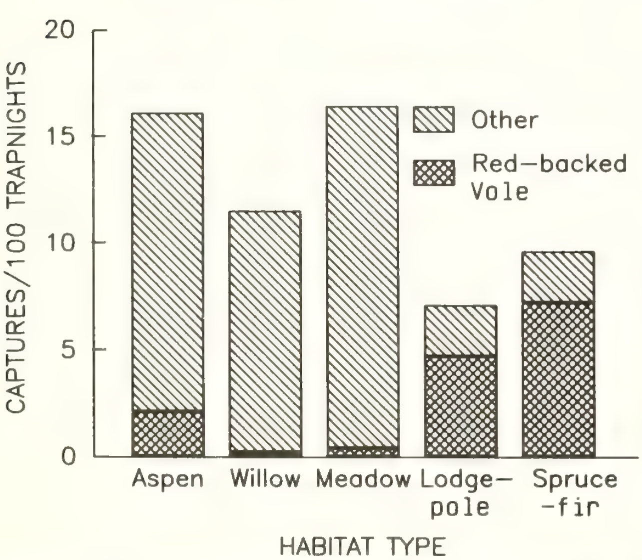

Figure 6.--Abundance of southern red-backed voles and other small mammal species in Rocky Mountain habitats (Brown 1967a).

Anderson and Patterson 1983, Baxter and Stone 1985) but these are based more on professional judgement and general ecology than on results of local research.

In one of the few bird community studies, Young (1977) examined bird diversity (numbers of breeding species) in relation to 14 structural features of subalpine forest. She found that diversity of tree diameters was the single best predictor of bird diversity ($R^2 = 0.73$); as diameter diversity increased, bird diversity increased. Winn (1976) found, in contrast, that plant species diversity was the best predictor of bird species diversity.

As summarized by Scott et al. (1980), cavity-nesting birds comprised about 25% of the total breeding density of birds in subalpine forest (range = 13-40%). Thus, the abundance and characteristics of snags is an important forest attribute. Scott et al. (1978, 1980) surveyed snags at the Fraser Experimental Forest in Colorado and found that lodgepole pine, Engelmann spruce and subalpine fir snags greater than 12 inches dbh were used for nesting at rates greater than expected from their availability, and that broken-topped snags of all three species also received the greatest use. Overall, only 3% of 1,722 snags sampled had nest cavities, but 33% of broken-topped snags > 12 inches d.b.h. had cavities.

Habitat associations of small mammals seem to have received more study, but detailed analyses of mammal communities in relation to habitat structure are lacking. The following examples illustrate typical studies from subalpine forests. Spencer and Pettus (1966) examined habitat associations of five shrew species. The presence of surface water was an important habitat feature. Dusky and dwarf shrews tolerated the most xeric conditions, masked and pygmy shrews were intermediate, and the water shrew was found only in close proximity to water. Brown (1967b) found a much greater abundance of masked shrews in boggy habitats, whereas dusky shrews were predominant in upland sites and pygmy shrews were associated with rock outcrops. The importance of moisture was also noted by Armstrong (1977).

Brown (1967a) related abundance of mice to proximity of water and cover density. Jumping mice and long-tailed voles were more abundant near water; montane voles, southern red-backed voles, and deer mice were more abundant on sites further from water (> 175 m away). Jumping mice, long-tailed voles, and montane voles were most abundant in dense understory cover; red-backed voles and deer mice were about equally abundant in all cover classes. Sleeper (1979) examined small mammal population fluctuation in relation to snowpack over a 6-year period, and found significant and negative correlations between summer population numbers and snowpack the previous winter for five mammal species. Deep snowpack appeared to depress population numbers. In a detailed study of the winter ecology of the southern red-backed vole, Merritt (1976, 1985) and Merritt and Merritt (1978) found that autumn freeze and spring thaw were periods of greatest hardship and poorest survival. Telleen (1978) compared the distribution of least and Uinta chipmunks at Rocky Mountain National Park, and reported that the Uinta

chipmunk preferred closed canopy forest with an open understory, whereas the least chipmunk favored open canopy and closed understory.

Studies of habitat associations of reptiles and amphibians are virtually nonexistent in subalpine forest, primarily because reptiles and amphibians are virtually nonexistent. Baxter and Stone (1985) have summarized habitat associations of subalpine species in Wyoming; Hammerson and Langlois (1981) do so for Colorado, but their habitat descriptions are limited to lists of habitat types in which each species is known to occur. Haynes and Aird (1981), in one of the more detailed analyses of habitat requirements, found that the wood frog breeds primarily in small (<0.25 ha) natural ponds with emergent vegetation along a shallow north edge.

Responses to Disturbance

Fire

Fire-induced secondary succession in subalpine forest systems is accompanied by marked changes in bird and small mammal populations (Taylor 1971, Davis 1976, Roppe and Hein 1978, Ramsden and Lyon 1979, Taylor and Barmore 1980). In general, these studies show that biomass of birds and small mammals is greater in burned compared with unburned forest. Overall, biomass of birds is highest within the first 10 years following fire, then decreases during the intermediate period from 50-100 years following fire when, in the absence of further disturbance, stands are often overstocked and stagnated (fig. 7). Biomass increases thereafter to prefire levels. The general pattern varies, however, among birds in various feeding categories. Ground-foraging and timber-drilling birds are more abundant in burned forest, but seed- and insect-eating birds associated with the overstory canopy are more abundant in unburned forest (Taylor and Barmore 1980).

Similar patterns are also found among small mammals. Roppe and Hein (1978) estimated a biomass of small mammals of 1,020 g/ha on an 8 year-old burn compared to 764 g/ha

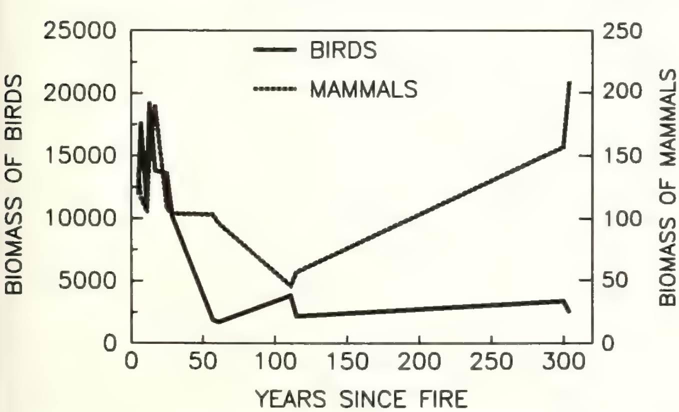

Figure 7.--Biomass (g/40) of birds and small mammals on various burned study areas (Taylor 1971).

in unburned forest. Red squirrels and showshoe hares, not counted in these totals, were absent in the burn. Shrews, golden-mantled ground squirrel, deer mouse, heather vole, and long-tailed vole were all more abundant on the burned plot, whereas southern red-backed vole was rare on the burn and abundant in the unburned forest. Chipmunks were equally abundant in both burned and unburned habitats. Taylor (1971) found that small mammal biomass, like that of birds, was lowest during the intermediate period of postfire succession (fig. 7).

Timber Harvest

Birds seem to respond to timber harvest in patterns similar to their responses to fire. Austin and Perry (1979) found much higher densities of birds in 25- and 15-year-old clearcuts (302 and 538 birds/100 acres, respectively) than in mature forest (134 birds/100 acres). Most of these differences were due to higher abundance of American robin, Cassin's finch, pine siskin, and chipping sparrow on the clearcuts. These are ground-foraging seed and insect eaters that are favored by opening the overstory canopy. In this study, only the hermit thrush (a ground-insect forger that nests in closed canopy format) and ruby-crowned kinglet (a canopy-insect forager) were more abundant in the mature forest.

Scott et al. (1982) found no significant short-term change in total numbers of birds during 2 years immediately after 36% of a 40-ha timber stand was harvested in 12 small clearcuts on the Fraser Experimental Forest. They did find significant declines in abundance of golden-crowned and ruby-crowned kinglets; no birds increased significantly, but the Lincoln's and song sparrow were observed on the harvested drainages following treatment but had not been observed prior to treatment.

The influences of slash disposal and other site preparation practices on the post-harvest suitability of stands were studied by Davis (1976). He found that increased logging residue, standing dead timber, and understory plant diversity all led to higher abundance of birds on clearcuts. Keller (1987) compared bird abundance in subalpine forest fragmented by recent stripcuts or small patchcuts and compared results to unharvested controls. She identified 6 species that were less abundant in timber adjacent to harvest in at least 1 year during her 2-year study, 4 that were more abundant, and 3 that showed no change. She concluded that brown creeper and red-breasted nuthatch (bark foraging species) were most sensitive to nearby harvest through reduction in their total foraging habitat area.

Studies of small mammal populations following harvest show variable results. Several studies report a net decrease in total abundance on clearcut sites compared to uncut sites (Porter 1959, Spencer and Pettus 1966, Austin and Urness 1977, Scrivner and Smith 1984), two studies report a net increase (Davis 1976, Ramirez and Hornocker 1981), and two studies showed no net change Campbell and Clark 1980, Scott

et al. 1982). The response of individual species was more consistent. Southern red-backed voles, for example, are consistently reported as much lower or absent in clearcuts, whereas deer mice, vagrant shrews, and least chipmunks are consistently more abundant in clearcuts. As reported among birds, site preparation and the nature of residual vegetation following logging are important in determining the suitability of post-harvest habitat for small mammals. Several studies (e.g., Davis 1976, Campbell and Clark 1980, Ramirez and Hornocker 1981) found a greater abundance of small mammals on clearcut sites with greater volume of slash or with thicker residual understory vegetation.

CONCLUSIONS

Studies of nongame wildlife in the central Rocky Mountains reveal that subalpine forests support low numbers of species and low population sizes of most species relative to other habitat types in the Rockies, and relative to other coniferous forest systems in North America. This rather depauperate fauna may be due to climatic extremes typical of the subalpine zone and the resulting low productivity of the forest. The few species that are abundant in subalpine forests tend to be widespread in distribution and are abundant in other forest types as well. Several species, including birds listed in table 2 and mammals such as the southern red-backed vole and marten, reach their peak in subalpine forest. Because of the extreme climate and the variability of snowfall and other weather factors from year to year, annual variation of population sizes of subalpine wildlife is great, suggesting that those species that winter in subalpine habitats may more often be limited by abiotic factors than by habitat.

Habitat associations of subalpine wildlife have received some study, but a great deal more research is needed. In particular, I found no studies of habitat associations of bats, a group that includes 14 species in Rocky Mountain forests but about which very little is known. There have been no long-term studies of nongame populations in relation to vegetation succession following fire or logging. Detailed quantitative studies of forest structure in relation to vertebrate community structure are lacking although some studies are underway. Much better information is needed on the distribution and occurrence of nongame wildlife species in the National Forests and Parks. The recent study by Newmark (1987), purporting to show evidence of losses of up to 43% of the original species among 14 National Parks in western North America, highlights the need to conduct a well-organized survey or inventory of the status of vertebrate species in our managed lands.

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Do We Know Enough to Manage Subalpine Wildlife Habitats? -- It All Depends

Jack Ward Thomas[1]

Abstract.--Subalpine ecosystems in the west have been largely immune from management action save grazing and recreation management. This situation has changed as access to such areas has improved and perceived demands for products of water, wood, wildlife, forage, and recreation have increased. Very little ecological research has been conducted in this ecosystem compared to lower elevation systems. Management of these areas, however, seems unlikely to be deterred by this relative paucity of detailed knowledge of ecosystem function. The political decision is to proceed with manipulation of these ecosystems and it is essential to bring the best knowledge available to bear on the issue and to proceed post haste with intensified research in the areas where knowledge is most critical and most lacking.

The question--do we know enough to manage subalpine wildlife habitats--should be expanded to include the adequacy of our knowledge to manage subalpine ecosystems for any purpose. Whether that management is labeled forest, watershed, wildlife habitat, or something else matters little. It seems that the time for management of subalpine ecosystems has come. These ecosystems have been largely excused from all but grazing and recreation management in the past because of their high elevation; relatively low annual biomass production; better, more abundant similar resources at lower elevation on more gentle terrain; lower demands for the resources available from such land, and--most of all--the lack of access for people and machinery to such areas.

Inexorably, these circumstances have changed and the opportunity and an increasing likelihood for management (i.e., manipulation) now exists. If past is indeed prologue, opportunity equates, sooner or later, to management to some degree for some purpose. Remember the cry of the seekers in the children's game of hide and seek when the count down was finished? "Here we come! Ready or not!" Just when we know enough to manage lies like beauty, in the eye and mind of the beholder.

As knowledge is never perfect nor complete nor adequately synthesized, there is risk in any land management action of damaging the ecosystem involved--perhaps irretrievably. There seems to be an array of interest groups when it comes to how much such risk is acceptable when breaking new ground in forest management. Those groups with the most to gain seem the most willing to take risks, and those with the most to lose are the least willing to risk much. Scientists, of course, are the most conservative of all, for two reasons. First, they probably perceive more complexity and unknowns in forest management than others. And second, they are more aware of just how unlikely it is that ecosystem response to management actions can be accurately predicted over the long run due to the cumulative effects of one management action after another after another over a prolonged period. The question of cumulative effects of management looms like a specter in the fog--not clearly discernable, but none-the-less formidable, and enough to instill a profound sense of caution.

A quick perusal of the literature suggests that we know much less about ecosystem function--certainly about wildlife habitat--in the subalpine areas of the West than we do about lower elevation ecosystems. This is probably due to the same reasons, mentioned earlier, that we are just now moving to management of such areas. There is one other reason--support for research in the subalpine ecosystems has been sparse. Research activities in ecosystem function and forest biology have been concentrated on lower elevation ecosystems where land management manipulations have been more fully implemented, problems have clearly emerged, and there is demand for better understanding of the situation.

It is difficult to obtain research support to develop knowledge ahead of the need for such knowledge. However, management action in the absence of adequate knowledge always either produces problems that need solutions, or creates the need for more specifics, such as coefficients to be used in

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models--or both! These problems or needs then generate the required political support for research. That seems generally the case with subalpine ecosystems. There has been inadequate research to minimize risks and maximize predictive capabilities from results of management action. Yet, the time for increasing management of subalpine systems seems at hand.

There are exceptions, fortunately, and the research that has been conducted on the Fraser Experimental Forest is one. The perceived need for increased water supplies for the developing megalopolis along the foothills of the eastern Rocky Mountain front provided the impetus for research to determine how to manipulate subalpine forests to enhance water flows, or control timing of those flows. The wildlife researchers who were able to piggy-back wildlife research studies onto these experimental timber manipulations (see Crouch, this symposium) should be commended for their foresight in seeing the ultimate need for such information, and for their ability and willingness to exploit the situation.

But, the question still remains--do we know enough to manage subalpine wildlife habitats?--without definitive answer. The answer must be that it all depends on the circumstances. For the wildlife biologist or any other resource management professional, this is akin to the much-maligned concept of situational ethics.

Let me illustrate from my own experience. The fir forests of the Blue Mountains of Oregon and Washington were hard hit by an outbreak of Douglas-fir tussock moth during 1971-1974. It was deemed necessary to salvage timber on large areas of essentially virgin forests. Four Forest Service forest supervisors asked to meet with me and a group of biologists from the Forest Service and Oregon Department of Fish and Wildlife. They described the impending salvage program, and asked advice on how the program might be modified to yield the best possible result in terms of wildlife habitat. As spokesman for the biologists, I decried the paucity of information available on wildlife habitat relationships in the vegetative types concerned, and concluded that the salvage action was premature. The senior forest supervisor, rather politely, informed me that they were not asking us for permission to conduct salvage logging. That decision had been made. They were asking for help with detemining how the operations would take place. If we had nothing to contribute, they would proceed considering advice from other natural resource specialists who did have something to say.

The biologists called "time out" and went into a huddle. Given the choice between participating in the design of the salvage operation and standing aside, we quickly decided, considering the alternatives, that enough was known to manage the affected wildlife habitats. Did we know enough to manage the wildlife habitats concerned? The answer, obviously, depended on the circumstances. We concluded it would be far better to combine our efforts and put forward the best synthesis of existing knowledge and experience concerning wildlife habitats we could, rather than stand aside decrying the miserable state of knowledge. In the final analysis, after the salvage operations were complete, the participants were convinced that wildlife habitat considerations were much better served than they would have otherwise been.

These initial guidelines for considering wildlife habitats during the salvage of tussock-moth-damaged timber eventually evolved into Wildlife Habitats in Managed Forests--the Blue Mountains of Oregon and Washington (Thomas 1979). This volume presented the available information on the relationship of resident terrestrial vertebrate species to plant communities and successional stages (or structural conditions), described special habitat features, and presented habitat modeling information for species to be featured in management. The publication has subsequently been credited as a stimulus for the Forest Service's ongoing Fish and Wildlife Habitat Relationships Program.

Since that time, similar efforts have been completed dealing with western Oregon and Washington (Brown 1985), the western Sierra Nevada mountains (Verner and Boss 1980), New England (DeGraaf and Rudis 1986), the Great Basin in Oregon (Maser and Thomas 1983), and Colorado (Hoover and Wills 1984) among others less formally published. A number of these efforts address, albeit peripherally, the habitat relationships of wildlife species resident in subalpine forests. Obviously, then, wildlife biologists do have some insights into how the impacts of various management actions in subalpine areas might be predicted and evaluated.

Perhaps the question should be--"Do we know enough to manage subalpine wildlife habitats with a high degree of confidence?" With, perhaps, the exception of a few species, the answer must be a rather emphatic "no." The information bases on wildlife habitat relationships mentioned earlier are a compilation of information and opinions from a variety of sources which may not be (1) specific to the subalpine ecosystems in question, or (2) particularly germane to the categorization of the data in the synthesis. Further, all the data and opinions used in the synthesis have been through the "filters" of the compilers of the synthesis, and colored by their training and experience. In many cases, gaps in existing published information (which are relatively large in the case of subalpine forests compared to lower elevation forests) were filled by a concensus of opinion of the participants in the synthesis process.

These synthesis efforts should be considered a beginning of the process to produce a state of knowledge necessary to allow management of subalpine habitats with a high degree of predictability in terms of ecological response. The participants in these pioneering synthesis efforts are, usually, the first to insist that these efforts be considered as working hypotheses--places to start, a guide to future research, and a good faith effort to participate in the unfolding drama of forest management. The alternative is to be either observers or largely unheeded critics.

These first efforts at synthesis of forest wildlife habitat relationships are probably weakest when it comes to dealing with subalpine ecosystems. Why? There is much less research done on wildlife habitat relationships in these forests than in

lower elevation forests. This relative paucity of information on wildlife habitats in subalpine areas--particularly as it relates to management manipulations of forests--should raise a flag of caution to managers. This flag of caution should be magnified in effect when it is considered that subalpine ecosystems in general (not just in terms of wildlife habitat), are relatively poorly understood.

It is obvious, however, that subalpine ecosystems are relatively fragile--the last transition from forests to the non-forested alpine zones. Such forests exist on relatively thin and poorly developed soils of low fertility, and endure severe climates and short growing seasons. Subalpine forests are much less forgiving of a manager's mistakes than the lower elevation forests that have provided most of our experience with forest and wildlife management.

So, we come again to the question--"Do we know enough to manage subalpine wildlife habitats?" The answer is "yes" and "no." We know enough to participate if management of such habitats is taking place. But, managers need to heed the whisper in their ears that warns that knowledge is not adequate to predict with confidence, over the long term, the effects of forest manipulation on most resident wildlife.

If there seems a high likelihood that subalpine forests of the mountain West will be manipulated within the foreseeable future for whatever purposes, it behooves us to concentrate more research effort on the entire subalpine forest ecosystem, not only in the area of wildlife habitat. It is likely that historians concerned about such things will identify the Fraser Experimental Forest as a cradle of such efforts. And, I hope they will say that what occurred up until 1987 was merely the beginning.

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A Preliminary Economic Assessment of Timber and Water Production in Subalpine Forests

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Abstract--Management costs and timber and water benefits of intensive management of a subalpine forest area in the Upper Colorado River basin were estimated. The water benefits were estimated with the use of a water basin model that indicated disposition of streamflow increases throughout the Colorado River Basin. This preliminary analysis indicates that the primary benefits of streamflow increases from intensive forest management in the Basin are in nonconsumptive water uses. The economic viability of intensive forest management was found to be very sensitive to costs of road construction and to estimates of values of water yield.

Watershed research has shown that vegetation management in some vegetation types can increase streamflow (e.g., Anderson et al. 1975, Hibbert 1979). Research at the Fraser Experimental Forest (Troendle 1983) in the spruce-fir type provides one of the most convincing examples of the potential for increasing water yield. Such research results have been received with interest by some water users in arid areas of the western United States, who look to application of the research results on an operational basis to alleviate current or expected water shortages (e.g., Cortner 1978).

An assessment of an operational program to increase water yield on public land should of course take into account the full set of costs and benefits in the context of multiple use management. The agency's monetary cost to implement such a program should be computed, and the onsite and offsite beneficial and adverse impacts should be estimated and valued. The onsite impacts include the effect on timber production, livestock grazing, wildlife populations, soil productivity, and scenic quality and recreation use. The offsite effects include changes in consumptive and nonconsumptive water use, changes in water quality, and lumber production. Thus, a comprehensive assessment of watershed management is a major effort.

Few published studies have analyzed the costs and benefits of watershed management for increased streamflow, and none have attempted a comprehensive assessment. For the spruce-fir type, however, two recent papers by scientists at Resources for the Future (Krutilla, Bowes, and Sherman 1983, Bowes, Krutilla, and Sherman 1984) have provided a good beginning. These papers compared the economic value of timber production and streamflow increases that would follow a vegetation management regime in the Colorado River Basin with the costs of management, including road construction costs.

This paper is also limited to impacts on timber and water yields. It builds on the Resources for the Future work (especially the paper by Bowes, Krutilla, and Sherman, or BKS) and another recent study that looked closely at the disposition of streamflow increases in the Colorado River Basin (Brown, Harding, and Lord, in press, or BHL). BHL modeled the storage, routing, consumptive use, and loss of flows in the Colorado River Basin with and without flow augmentation from vegetation management at the headwaters of the Colorado River. The difference between the with and without cases indicated the disposition of the additional streamflow.

The current study adopted the timber management regime and associated onsite yields posited by BKS, and the Colorado River water basin modeling of the BHL study. In addition, the effects of streamflow increases on two nonconsumptive water uses, hydropower production and dilution of total dissolved solids (tds), were estimated.

The paper first describes the timber treatment and its costs and yields. Next the water model is described, and the effects of streamflow increases on water use are presented. Then the timber and water yield increases with treatment are expressed in monetary terms, and the monetary costs and benefits of a vegetation management program are compared, first for

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current levels of water use and then for a future level. Finally, qualifications to the analysis are listed.

Timber Harvest

For this analysis, a lodgepole pine stand with a site index of 60 was assumed to be harvested on a 120-year rotation. Following road construction, one-third of this stand was harvested in small patches, followed by rapid natural regeneration. The harvested area received a precommercial thin in 30 years, commercial thins in 60 and 90 years, and a regeneration harvest in 120 years, whereupon the cycle would repeat itself. Thinnings were to a growing stock level of 80. Commercial harvests were of trees of at least 6.5 inches d.b.h., to a 6-inch top. From BKS, the four commercial harvests were assumed to yield 3.6, 2.6, 4.6, and 16.8 Mbf per harvested acre, respectively (table 1). Another one-third of the stand received these treatments beginning in year 30, and the final one-third received the treatments beginning in year 60 (see table 1 of BKS). On average, these treatments yielded 124 boardfeet per acre per year.

The following treatment costs, in 1982 dollars, were assumed: sale preparation and administration costs of $16 per Mbf (from BKS), precommercial thinning costs of $95 per acre (BKS), and logging and hauling costs for both commercial thins and regeneration harvests of $110 per Mbf (U.S. Forest Service Rocky Mountain Region records). The costs for the first one-third of the stand, ignoring road costs, are summarized in table 1. Costs for the other two – thirds are identical, but lagged 30 or 60 years. Costs of road construction, maintenance, and reopening received special attention by BKS because they vary so widely from one situation to another and because of the difficulty of choosing the most realistic road length and type, and the most likely slope of the terrain, for the study area. BKS's road costs, discounted at 4%, are reproduced in table 2.

Table 1.--Yield and cost for even-aged management of lodgepole pine stand.[a]

Year	Activity[b]	Yield[c] (Mbf/acre)	Cost[d,e] ($)
0	HVST	3.6	126/Mbf
30	PCT[e]	0.0	95/acre
60	THIN[e]	2.6	126/Mbf
90	THIN[e]	4.6	126/Mbf
120	HVST	16.8	126/Mbf

[a]Site index of 60.

[b]HVST is regeneration harvest, PCT is precommercial thin, and THIN is commercial thin.

[c]Trees 6.5 inches d.b.h. and larger to 6-inch top.

[d]1982 dollars, ignoring road costs.

[e]To a growing stock of 80.

Table 2.--Road cost per acre harvested by type of road, type of terrain, and length of road.[a]

Miles[b]	Type of road: Temporary	Intermittent	Seasonal	Surfaced
	Gentle slope (0.15%)			
2.5	47.47	70.61	99.83	121.07
3.5	66.46	98.86	139.76	169.50
4.5	85.43	127.11	179.69	217.93
5.5	104.41	155.36	219.62	266.36
6.5	123.39	183.61	259.55	314.79
7.5	142.37	211.86	299.48	363.22
8.5	161.35	240.11	339.41	411.65
	Moderate Slope (15.40%)			
2.5	64.19	77.56	107.62	128.89
3.5	89.86	108.59	150.69	180.44
4.5	115.54	139.62	193.75	232.00
5.5	141.21	170.65	236.81	283.55
6.5	166.88	201.68	279.87	335.10
7.5	192.00	232.71	322.93	386.65
8.5	216.47	263.74	366.00	437.47
	Steep Slope (<40%)			
2.5	91.64	96.91	138.89	167.94
3.5	128.29	135.68	194.44	235.13
4.5	164.94	174.45	250.00	302.31
5.5	201.59	213.22	305.56	369.49
6.5	238.24	251.99	361.12	436.67
7.5	274.89	290.76	416.68	503.84
8.5	311.54	329.53	472.24	571.02

[a]Reproduced from Bowes et al. (1984). Costs of road construction, maintenance, and reopening in 1982 dollars, discounted at 4%. Construction was assumed to be completed in year 0, before harvests began.

[b]Miles of road per square mile of land accessed.

Water Yield

The general approach to estimating the benefits of the streamflow increases was to determine the disposition of the flow increases, and then to assign marginal dollar values to the used water quantities. The disposition of the increases was determined by simulating water flow, storage, use, and loss within the entire Colorado River Basin (fig. 1) with and without the flow increases, and subtracting the "without" results from the "with" results. This was done for a 72-year period corresponding to available flow records.

Existing water storage and delivery facilities of the Basin were taken as given for the study. Management of these facilities was assumed to proceed according to existing legal and administrative institutions. Thus, intrastate water allocation was assumed to follow the doctrine of prior appropriation, and interstate allocation to follow existing compacts, court decisions, and administrative decisions, as described by BHL.

The Colorado River system was simulated with a linear programming network optimization model. The model, an adaptation of MODSIM (Shafer 1979, Labadie et al. 1983) and

Figure 1.--Colorado River Basin.

its predecessor SYMYLD (Texas Water Development Board 1972), uses the out-of-kilter algorithm (Clasen 1968, Barr et al. 1974) to perform a static optimization at each time step that mimics the system of priorities for water allocation in a river basin network. The model has three basic tasks: (1) manage input and output of data and control information, (2) convert a problem stated in hydrological terms into one amenable to solution by the out-of-kilter algorithm, and (3) use the algorithm to solve the network flow problem. The structure of the model is described by BHL, but some aspects of the model are summarized here.[2]

Water movement and disposition in the Colorado River Basin were modeled by aggregating sufficiently over time and space to conform to the limitations of the model. Each year was represented by four time steps representing the fall (October-December), winter (January-April), runoff (May-July), and irrigation (August-September) seasons. The Basin's 10 major reservoirs were represented by 7 reservoirs in the model. Consumptive use areas were combined into 22 points of use. Inflow, flow gains, and flow losses were combined into 21 points of natural flow change.

[2]The U. S. Bureau of Reclamation has a very detailed and complex simulation model of the Colorado River Basin, called CRSS (DOI 1985). For this application, the model described here was used because it was more tractable and more easily adapted to examination of the effect of flow increases. However, future interest in the routing of flow increases may warrant comparing the results of this analysis with those obtained using the BOR model.

Reservoirs and Hydropower Production

The reservoirs of the model contain a total live capacity of 60,028,000 acre-feet (table 3). Lake Mead was separated into its conservation and flood control portions to allow simulation of the separate operating rules that apply to the two storage categories. Hydroelectric power is produced at all reservoirs except Navajo. Energy production was modeled as a function of (1) the amount of water that passed through the turbines, (2) the feet of effective head that the water dropped, and (3) power plant efficiency, capacity, and minimum head (table 3). Overall hydraulic, mechanical, and electrical efficiency of all plants was assumed to be 90% (BKS). Energy production computations are listed in the Appendix.

The gross time step used in this study may have resulted in an unrealistically high estimate of hydroelectric power production. The capacity constraints were compared with flows from the dams for each period; some water may have been assumed to run through the turbines to produce power when it would in real time have been released via the spillways.

Table 3.--Reservoir storage and power production.

Reservoir	Live storage capacity[a] (1,000 acre.feet)	Generator[b] capacity (1,000 KW)	Min. head[c] (feet)	Max. head[c] (feet)
Upper Basin				
Fontenelle	250	10	80	110
Flaming Gorge	3,749	108	260	440
Blue Mesa	815	60	236	360
Morrow Point	115	120	353	430
Crystal	18	28	166	224
Navajo	1,696	--	--	--
Powell	25,002	1,206	385	568
Lower Basin				
Mead conservation	20,659	1,452	420	585
Mead flood control[d]	5,350	--	--	--
Mohave	1,810	240	89	136
Havasu	619	120	60	80
Total	60,082			

[a]Computed as total capacity minus dead storage.

[b]Source: Annual Report 1985, Western Area Power Administration (WAPA), U.S. Department of Energy.

[c]Source: Input parameters for the CRSS model (DOI 1982).

[d]Emptied in the fall season to simulate the requirement to provide at least 5.35 million acre.feet of flood control storage on January 1 of each year (DOI, 1982). Releases from this pool were also considered available for power production.

Reservoir evaporation was computed at the end of each time period from surface area/volume relationships and unit evaporation rates adopted from the U. S. Bureau of Reclamation's Colorado River Simulation System (CRSS) model (DOI 1982).

Total Dissolved Solids

Lower Basin salt concentrations, or total dissolved solids (tds), were computed by tracking salt mass and water volume entering, leaving, or remaining in Lakes Powell and Mead, plus salt and water entering the river below Lake Mead, in each time period. The relationships used for tds computations are included in the Appendix.

An average of 9 million tons of salt enter the Colorado River per year (DOI 1983). We assumed that this mass was constant per year, and that 8 million tons entered above Lake Powell and 1 million tons entered below Lake Mead. Furthermore, we assumed complete mixing of salts in Lakes Powell and Mead per period. In addition, we assumed that tds of the streamflow increases was 50 mg/l and that the tds of water stored in Lakes Powell and Mead at the beginning of the simulation was 678 mg/l, the mean tds level for the 1973 to 1983 period (Miller et al. 1986).

The assumptions of constant salt contribution each year and rapid mixing within the reservoirs are known to be incorrect. First, salt in return flows obviously varies with quantity withdrawn. Second, Mueller and Osen (1987) found that the quantity of dissolved solids entering the Colorado River Basin with natural (not return) flows varies with flow, and that the relationship between flow and salt contribution differs by location. Third, Gardner (1983) reports that, while relationships are not well understood, experts assume a lag of several years before a change in tds levels entering Lake Powell are realized in the Lower Basin. Accounting for these nuances was beyond the scope of this preliminary study; however, it should be noted that a lag in salt mixing in reservoirs would tend to spread the annual fluctuations in salt inflow over several years, so that the effect of one of our assumptions is counteracted by the other assumption.

Flows

"Normal," or pretreatment, flows were based on a 72-year period (1906-1977) of monthly reconstructed virgin flows developed by the USBR for 28 stations throughout the Basin. These data were combined to conform to the four seasons and 21 inflow points of the model.

Streamflow increases from vegetation management entered the network in the Upper Colorado River (fig. 1). Based on experience at Fraser Experimental Forest (Troendle 1983), the increases were assumed to come entirely during the runoff (May-July) period. The annual flow increase per acre was estimated as a product of (1) expected annual increase assuming average precipitation conditions and (2) a factor expressing the difference between actual and average precipitation conditions. The expected increases were taken from BKS, who computed them for the timber harvest regime described above based on the flow increase model of Leaf and Alexander (1975). The annual adjustment factors were computed as the ratio of annual to mean annual flow on the Colorado River at Glenwood Springs, downstream from the treatment area. Thus, the annual flow increase was assumed to be directly proportional to annual normal flow. For example, a year that experienced a normal flow 50% above average would also receive a flow increase 50% above the mean flow increase expected at that stage of the treatment regime.

To provide a realistic context for modeling, it was assumed that the 334,600 acres vegetated with harvestable species in harvestable areas that drain the Arapaho National Forest above Kremmling, Colorado (as delineated by BHL) were available for treatment, and that those areas all experienced the streamflow increases expected from harvest of the lodgepole stand described above. The Arapaho National Forest was chosen because of its significant precipitation and resultant potential for streamflow increases with vegetation management, and its proximity to the Fraser Experimental Forest, where the water yield model used to predict streamflow increases was developed. A large area was chosen in order to posit a sufficiently large streamflow increase for water basin modeling purposes.

Mean annual flow increases varied from 1.3 inches just before the 30th year of the timber management regime to 3.1 inches just after the 60th year harvests (BKS, table 4). Annual adjustment factors ranged from 0.38 to 1.91. When the per acre yields were then multiplied by the 334,500 acres assumed available for treatment, this procedure yielded annual flow increases that ranged from 15,611 to 101,434 acre-feet, with a mean of 55,583 acre-feet. The mean streamflow increase is equivalent to 0.4% of mean annual virgin flow at Lee Ferry over the historical flow record.

Water Requests and Allocation Priorities

The Upper Basin was represented by 15 consumptive use areas, corresponding to agricultural, municipal and industrial (M&I), and energy uses in each of 5 use areas: (1) the Upper Green River area above Flaming Gorge Reservoir in western Wyoming, (2) the Lower Green River area in western Utah, (3) the Yampa area in northwestern Colorado, (4) the Upper Colorado River areas near Grand Junction, Colorado, and including exports to the Colorado Front Range, and (5) the San Juan drainage area east of the Four Corners.[3]

The Lower Basin area was represented by six water request areas, one for agriculture and one for M & I use in Nevada and Arizona along the Colorado River, one for southern Arizona via the Central Arizona Project (CAP), and three for California (table 4). The California areas distinguish (1) agricultural and (2) Metropolitan Water District (MWD) authorized use under the Boulder Canyon Act of 1928 (as reinforced by the 1963 U.S. Supreme Court decision in California vs. Arizona), and (3) use by MWD in excess of that act. Mexico is the other consumptive use area.

Table 4.--Annual consumptive use requests for water under current and future conditions (1,000 acre-feet).[a]

Use area	Current	Future
Upper Basin		
Upper Green	354	673
Lower Green	674	1168
Yampa	155	198
Upper Colorado	1,761	2,369
San Juan	510	849
Total	3,454	5,257
Lee Ferry Flow-through	8,231	8,231
Lower Basin		
Arizona/Nevada Agriculture[b]	1,310	1,250
Arizona/Nevada M & I[b]	198	384
Central Arizona Project (CAP)[c]	765	1466[d]
California Agriculture	3,902	3,902
California Metropolitan Water District (MWD)	498	498
MWD Excess[e]	729	729
Total	7,402	8,229
Mexico	1,500	1,500

[a]Principal source: U.S. Department of Interior (1982). These several requests were apportioned to seasons, and assumed to be constant over the 72-year simulation.

[b]Located principally along the Colorado River.

[c]Including both agricultural and M & I uses.

[d]Computed as the difference between the total Arizona allocation (2,800,000 acre-feet) and the non-CAP Arizona diversion (1,334,000 acre-feet).

[e]Computed as the difference between the highest historical delivery by MWD (1,227,000 acre-feet) and MWD's authorized use under interstate agreement (498,000 acre-feet).

In addition to the consumptive use requests, a flow-through demand at Lee Ferry accounted for the Upper Basin obligation to the Lower Basin. This obligation reflects the apportionment established in the Colorado River Compact of 1922, and assumes that the Upper Basin contributes half of the Mexican delivery commitment.

Water was allocated within the Basin according the priorities established by interstate compacts, treaties with Mexico, court decisions, and operating rules for the storage and delivery of the water. The Lee Ferry flow-through and Mexico delivery obligations were satisfied first, followed by Upper Basin consumptive use requests. All Upper Basin consumptive use requests were given identical priority. Upper Basin reservoirs were filled after Upper Basin consumptive use requests were met, with reservoirs at higher altitudes filled first to minimize evaporation. Priorities of consumptive use in the Lower Basin reflected the U. S. Supreme Court's 1963 decision in <u>Arizona</u> <u>vs</u>. <u>California</u>. The Lake Mead flood control pool was satisfied last and was emptied in the fall season. To summarize, the priorities are as follows:

1. Lee Ferry delivery; Mexico delivery
2. Upper Basin consumptive uses
3. Upper Basin storage
4. Lower Basin consumptive uses except CAP and MWD excess
5. CAP use
6. Mead conservation storage
7. MWD excess use
8. Mead flood control storage

In keeping with current reservoir management in the Basin, priorities for water allocation for hydroelectric power production and Lower Basin salt dilution were not included in the network. Power production was assumed to be a subsidiary goal, which used water as it became available in the course of

[3]Aggregation of Upper Basin consumptive use into 15 use areas in the model may have caused shortages at some actual points of use to be overlooked. That is, although aggregate water supply of the use area may be sufficient to meet aggregate requests, the location of some actual points of use may be upstream of the actual water available to meet requests at those points.

meeting consumptive use requests in light of physical and institutional constraints on storage and delivery. Lower Basin tds was simply computed post hoc in order to estimate the cost to consumptive water users of the tds of their water.

Consumptive use estimates were taken largely from the monthly figures developed by the Bureau of Reclamation (DOI 1982) as input to the CRSS model. Upper Basin consumptive use requests currently total 3.5 Maf, and may reach 5.3 Maf in the future (table 4). The "current" levels reflect 1980 conditions, and the "future" levels reflect conditions that may exist in 2030 if current institutional arrangements remain unchanged and current Bureau of Reclamation forecasts are accurate. The requests are for consumptive use (i.e., diversion minus return flow). Mexico's consumptive use request of 1.5 Maf reflects the Mexican Water Treaty of 1944.

Three scenarios were simulated. Two of the scenarios assumed the current water request level and the third assumed the future request level (table 4). The two current scenarios differ in terms of the flexibility with which releases from Lake Mead are made to meet MWD water requests. Some flexibility is possible given the authority of the Secretary of the Interior to declare a surplus in Lake Mead and release water from the Mead conservation pool in excess of the release required to meet legal entitlements. Scenario 1 assumes a conservative interpretation of the Secretary of the Interior's discretion in such releases, limiting releases from the Mead conservation pool to meet California water requests to the legal entitlement of 4.4 million acre-feet. This policy does not allow any releases from the Mead conservation pool to meet MWD excess requests. Scenario 2 assumes that releases can be made to meet MWD excess requests if the Mead conservation pool is at least 75% full. Scenario 3 assumes the future water requests and the same flexibility in Mead releases as the second scenario.

Table 5.--Projected average annual Colorado River water disposition, hydropower production, and lower basin TDS levels.[a]

	Scenario 1: Current water requests without Mead flexibility[b]		Scenario 3: Future water requests with Mead flexibility[c]	
	Normal flows	Augm.[d] flows	Normal flows	Augm.[d] flows
Water disposition (1,000 af)				
Upper Basin				
Consumptive use	3,449	3,449	5,242	5,242
Shortage	2	2	17	17
Evaporation	749	750	628	634
Lower Basin				
Consumptive use	7,172	7,175	7,803	7,803
Shortage	225	222	422	422
Evaporation	1,455	1,460	875	888
Net change in reservoir content	37	39	.366	.343
Outflow to Mexico	3,296	3,341	1,978	1,991
Hydropower production (Million kWh)	14,944	15,009	11,971	12,058
Lower Basin TDS (mg/l)	628.7	626.4	689.6	687.4

[a]Reservoirs two-thirds full at beginning of simulation period.

[b]No releases from Mead conservation pool to meet MWD excess requests.

[c]Releases from Mead conservation pool to meet MWD excess requests if the pool is at least 75% full.

[d]Flows augmented by treatment of 344,600 acres on Arapaho National Forest.

Use of Streamflow Increases

Water allocation within the Colorado River Basin was modeled for a 72-year time span as if the 1906-1977 inflows were to repeat themselves beginning at the start of the simulations. Reservoirs were assumed to be two-thirds full at the beginning of the simulations, which understates current storage. The three scenarios were simulated with and without runoff increases that could be produced by applying the harvest regime described above to 334,600 acres of the Arapaho National Forest.

At current water request levels and without flexibility in releasing from Lake Mead to meet MWD excess requests (Scenario 1), shortages were substantial and concentrated in the Lower Basin. Upper Basin shortages averaged 2,000 acre-feet per year (table 5), and were restricted to the Yampa use area during the irrigation season in a few dry years. These shortages were not affected by the streamflow increases. Lower Basin shortages averaged over 200,000 acre-feet per year with or without flow increases, and were entirely in the MWD excess account. On average, 3,000 acre-feet per year of the increase was delivered to the MWD excess request account. This delivery is equivalent to 9 acre-feet per year per 1,000 acres of treatment (table 6). The increases did little to alleviate Lower Basin shortages because they seldom reached Lower Basin users during times of shortage. Because Lake Powell storage was sufficient to meet required releases to the Lower Basin without the flow increases, the increases accumulated in Lake Powell until they could no longer be stored. They were released or spilled from Powell during high flow years, which was typically when the Lake Mead conservation pool was also full and there were no shortages in the Lower Basin. Thus, the increases tended to flow on past Lower Basin diversions to Mexico. Occasionally, however, the streamflow increases were stored in the Mead flood control pool and released later the same year to meet MWD excess requests. On average, 5% of the increase was consumptively used, 11% evaporated, and 82% flowed to Mexico (table 6).

In addition, because the additional flow increased hydraulic head in Lakes Powell and Mead, and increased flow through the turbines, 194 more kilowatt hours (kWhs) were produced per acre of harvest. Finally, the flow increase

Table 6.--Projected average annual effect of vegetation treatment.

	Current water request level: Without flexibility in Mead releases (Scenario 1)	Current water request level: With flexibility[a] in Mead releases (Scenario 2)	Future water request level[a] (Scenario 3)
Timber production (bf/ac)	124	124	124
Water disposition (a-f/1,000 ac)[b]			
Consumptive use	9	0	0
Evaporation	18	38	57
Net change in storage	6	6	69
Outflow to Mexico	134	123	39
Total[c]	167	167	165
Hydropower production[b] (kWh/ac)	194	185	260
Reduction in Lower Basin[b] TDS (mg/l/1,000 ac)	0.007	0.006	0.007

[a]Releases from Mead conservation pool to meet MWD excess requests if that pool is at least 75% full.

[b]Based on treatment of 344,600 acres of the Arapaho National Forest.

[c]May not add to 166 because of rounding.

reduced Lower Basin tds levels by about 0.007 mg/l per 1,000 harvested acres (table 6).

With flexibility in Mead releases to meet extra-compact requests (Scenario 2), Lower Basin consumptive use requests were completely met, so the streamflow increases were not needed there. Upper Basin shortages were minimal, restricted to the Yampa use area, and not affected by the increases. Again, the increases were stored in Lake Powell until years of high flow, when they were released from Powell and tended to flow on to Mexico. Over the 72-year simulation, 74% of the runoff increases flowed to Mexico and 23% evaporated (table 6). Although not used consumptively, the flow increase raised hydraulic head and produced power upon passing through the turbines at Glen Canyon and Hoover Dams. The increase also lowered Lower Basin tds levels. On average, the increases produced 185 kWhs per harvested acre and reduced tds levels by 0.006 mg/l per 1,000 harvested acres (table 6).

At the future water request level, and with the flexible Mead release policy (Scenario 3), shortages averaged 17,000 acre-feet per year in the Upper Basin (table 5). The shortages occurred in several use areas, including the Upper Colorado. They occurred during the irrigation season only, however, so that the runoff increases were not available to offset them. Lower Basin shortages, all to the MWD excess account, were 422,000 acre-feet per year. They also were not affected by the flow increases because the shortages occurred during years when the Mead conservation pool was below the 75% cutoff for releasing to MWD excess.

Reservoir storage was considerably lower with Scenario 3 than with Scenarios 1 and 2 because of the higher consumptive use levels of Scenario 3. Because of the generally lower storage levels, much of the runoff increase with Scenario 3 accumulated in Lakes Powell and Mead (table 6). Because so much of the flow increases remained in storage, 35% of the increases evaporated, but hydraulic head in Lakes Powell and Mead was improved considerably. The effect of the increase in hydraulic head on hydropower production more than offset the decrease in hydropower production because less of the runoff increase was released from storage, so that the runoff increase produced 260 kWhs per harvested acre.

Economic Effect of Vegetation Management

The change in timber yield or water use with vegetation treatment, multiplied by the appropriate monetary estimate of the willingness to pay for the change, indicates the economic value of the change. Because the changes predicted here are sufficiently small relative to current production, the marginal values of current production are appropriate estimates of value of the changes in timber yield and water use. Subtracting any costs to bring about the change from the economic values would then yield the net return.

Marginal Values

Returns from initial harvests were assumed to be $135 per Mbf (log scale) at the mill, based on Rocky Mountain Region records (table 7). This return assumed a finished product value of $320 per Mbf minus manufacturing costs of $185 per Mbf. The $320 is a rough average of values that varied from $290 to $350 in the early 1980s.

Managed stands should yield higher values per board foot than the typical harvest of unmanaged stands. We used two different values for managed stands, a value of $169 per Mbf based on the assumption of a 25% increase in value with management, and a value of $225 per Mbf based on a 67% increase in value with management (the latter from BKS).

Ignoring road costs, the present value of the three initial harvests is $15 per acre (discount rate = 0.04). The present values of the precommercial thins and harvests of the regenerated stands are $4 and $8 per acre, depending on whether the lower or higher estimate of value increase with management is used. Thus, the low and high estimates of present value are $11 and $23 per acre, respectively. It is obvious that timber yields alone are insufficient to cover the costs of road construction listed in table 2.

Values for Upper Basin consumptive water uses and Lower Basin agricultural uses are not listed in table 7 because the streamflow increase did not affect the quantity of water in these uses. The high municipal and industrial (M&I) value was computed as the cost of alternative supply to the MWD of approximately $320 per acre-foot in 1982 dollars (from Wahl

Table 7.--Marginal values of timber and water (1982 dollars).[a]

Use	Low	High
Timber yield (per Mbf)[b]		
Initial harvests	135	135
Harvests of managed stands	169	225
Consumptive water use (per acre-foot)		
Lower Basin M&I	60	240
Hydropower (per kWh)	0.018	0.021.0.05[c]
Salt dilution (per mg/l)		
agriculture[d]	$(23{,}900\ e^{0.0052\ TDS})/TDS$	
M&I[e]	242,100[f]	381,000[g]

[a]Adjusted where necessary to 1982 using the GNP implicit price deflator.

[b]Value upon delivery to the mill, log scale.

[c]The exact value used in a given period at a given hydropower plant depended on its plant factor during that period. Larger releases, all else equal, produced a larger plant factor and a smaller unit value.

[d]Source: Anderson and Kleinman (1978). TDS in mg/l. Agricultural damages are assumed to begin at 800 mg/l TDS.

[e]These costs apply to the tds of the water consumed, which is typically lower than the tds of the Colorado River water because of mixing of Colorado River water with other supplies of lower tds.

[f]Source: DOI, cited in Miller et al. (1986).

[g]Source: Kleinman and Brown (1980).

and Davis 1986) minus the cost of pumping Colorado River water through the California Aqueduct ($80 per acre-foot, based on a requirement of 2,000 kWh per acre-foot, from Wahl and Davis 1986), or $240 per acre-foot. The low estimate of $60 per acre-foot is the annualized equivalent, at 4%, of the recent price of Colorado Big Thompson water shares of $1,500 per acre-foot.[4]

Availability of hydropower in a power network typically allows a reduction in power production at the more expensive thermal plants of the network. Thus, hydropower was valued at the cost savings at thermal plants. The low and high estimates of this cost savings differ in the extent to which they attempt to distinguish among the different kinds of thermal plants whose power is replaced when hydropower is available. The low estimate of the value of hydropower assumed, as did BKS, that all hydropower replaced coal -- fired power. Coal-fired power was valued at $0.018 per kWh, based on the average fuel costs of coal-fired steam-electric plants (U.S. Department of Energy 1985). The high estimate of the hydropower value assumed that the initial hydropower produced in any given period replaced power otherwise produced by combustion turbine plants, valued at $0.05 per kWh (U.S. Department of Energy 1985), and that additional hydropower replaced coal-fired power valued at $0.018 per kWh. This resulted in a range in unit value of hydropower from $0.021 to $0.05 per kWh depending on the production level at hydropower plants. See the Appendix for more detail on the derivation of the high value estimate.

The values of water in salt dilution reflect the cost that tds impose on water users. The cost to agriculture, from Anderson and Kleinman (1978), is an aggregation of individual cost functions figured for all major Lower Basin (excluding Mexico) agricultural areas relying on Colorado River water (table 7). This cost function, an increasing function of tds, applies only at tds levels above 800 mg/l. The Lower Basin M&I cost of $381,000 per mg/l reflects the discounted cost of reductions in the life of pipes and water using appliances (Kleinman and Brown 1980). Because there is considerable controversy over this cost estimate, a lower estimate of $224,100 per mg/l was also used (table 7). This estimate is an update to 1982 of a 1974 Bureau of Reclamation study, as reported by Miller et al. (1986).

The costs to M&I users were applied over the full range of tds levels, following d'Arge and Eubanks' (1978) report of fluctuating but generally rather consistent costs per mg/l over a range in tds from about 200 to 1,000 mg/l. Also, note that the M&I costs apply to the tds levels of the consumed water, which for the MWD and CAP diversions is a blend of Colorado River water and water from other sources of generally lower tds. The tds levels of the expected blends were estimated for the MWD and CAP, and the appropriate portions of the Lower Basin M&I cost were applied to these blends and to other Lower Basin M&I use areas.[5]

Results

The monetary values were multiplied times the annual quantity of use of the flow increase for each use category over the 72-year simulated period, and the resulting monetary estimates of benefit were discounted to the present. The results of this procedure were then expanded to represent the 120-year period used by BKS to simulate timber yields and management costs.

Economic returns per acre to timber and water yields from intensive vegetation management, ignoring costs of road construction, are listed for the three scenarios in table 8. Returns for Scenario 1 are listed by category, but only the total returns for the other two scenarios are listed. The treatment costs (for sale layout and administration, precommercial thinning, commercial thinning, and final harvest) were subtracted from the at-the-mill timber values to compute the timber returns, although those costs are actually joint costs of

[4]CBT shares sell in the Northern Colorado Water Conservancy District in what is probably the most active water shares market in the US. The price per acre-foot rose above $3,000 in 1980, but has since fallen to about $1,000 (Saliba, et al., in press). We chose $1,500 per acre-foot as a reasonable low end of the price range.

[5]The Lower Basin M&I cost was apportioned as follows: 78% to MWD, 11% to CAP, and 11% to other users along the Colorado River, principally in Las Vegas (d'Arge and Eubanks 1978). Tds of the blended water were estimated from an Environmental Defense Fund (1983) study for MWD and from personal communication with Dennis Sundie, Arizona Department of Water Resources, Phoenix, for the CAP.

Table 8.--Economic returns per acre from vegetation treatments for three scenarios, ignoring road costs (1982 dollars).[a]

	Low value estimates		High value estimates	
	Aver. ann. return	Present value[b]	Aver. ann. return	Present value[b]
Scenario 1 -- Current requests without flexibility in releases[c]				
Timber	0.44	11	0.93	23
Consumptive water use	0.51	13	2.05	51
Hydropower	3.49	87	3.49	87
Salt dilution	0.60	13	0.94	20
Total	5.04	124	7.41	181
Scenario 2 -- Current requests with flexibility in releases[c]				
Total	4.28	105	5.05	124
Scenario 3 -- Future requests with flexibility in releases[c]				
Total	5.74	115	6.55	121

[a]Returns over 120-year time period. Hydrologic results from 72-year simulations extended to 120 years for the purpose of present value computations by assuming mean annual results from the simulations apply to the subsequent 48 years.

[b]Discounted at 4%. Note that present values are sensitive to the timing of the returns, and therefore to the temporal characteristics of the hydrologic trace. The same annual flows in a different order could produce quite different present values.

[c]Flexibility indicates release water from the Mead conservation pool to meet MWD water use requests when that pool is at least 75% full.

timber and water production. Because assignment of joint costs is arbitrary, computation of the relative contribution of timber and water to net return is precluded. However, it is clear that, among the three uses of the additional streamflow, hydropower production contributes more to net return than consumptive use and salt dilution combined. Also, note that the return from hydropower production is the same for both low and high value estimates. The high value estimate yielded a higher estimate of the total value of hydropower production, but not of the value of the increase in production. This is because the streamflow increase was always used for hydropower production when the hydropower plants were producing at a sufficient level of capacity that the additional hydropower replaced only coal-fired thermal power production.

Average annual returns are lowest with Scenario 2, which does not benefit from either consumptive use of the flow increases, as does Scenario 1, or the increased electric energy production of Scenario 3. Assuming the low dollar values, average annual return per acre varies from $4.28 per harvested acre with Scenario 2 to $5.74 with Scenario 3 (table 8). With the high values, average annual return per acre varies from $5.05 with Scenario 2 to $7.41 with Scenario 1.

Discounting the returns at 4 percent, per acre present values over the 120-year time horizon range from $105 to $124 assuming the low value estimates, and from $121 to $181 assuming the high value estimates (table 8). Scenario 1 yields the highest present values for both sets of dollar value estimates. These discounted returns can be compared with the road costs of table 2. Assuming, for example, that 5.5 miles of road are required per square mile of accessed territory and that slopes are moderate, returns from timber and water yields are insufficient to cover road costs with any scenario given the low value estimates. Assuming the high value estimates, however, plus the same road densities and slopes, the returns of Scenario 1 are sufficient to cover costs of intermittent roads; returns of Scenarios 2 and 3 are still insufficient to cover road costs.

Because actual road costs vary significantly with remoteness of the harvest area, and required road type, this particular comparison is of limited practical importance. However, the comparison does point out the significant sensitivity of the results to the values assumed and to reservoir management flexibility.

Qualifications

The qualifications on use of this analysis include (1) reminders of what the analysis did not attempt to contribute to the decision regarding vegetation treatment, and (2) major assumptions upon which the analysis is based, that perhaps biased the results.

The analysis did not attempt to measure the effect of the roads and vegetation treatments on wildlife populations, or on scenic quality and recreation use, at treatment sites or along water courses and impoundments. Concern for such effects should be included in any complete analysis of the treatments. In addition to such omissions, it is worth mentioning that the analysis is limited in that it did not examine other alternatives for (1) increasing timber products or substitutes for timber products or (2) increasing water yield or otherwise dealing with the expected water shortage. Even if the benefits of a vegetation treatment regime were shown to be greater than the costs, there may be some more efficient approach to the same goals.

The model upon which the analysis of water storage and routing is based is a major simplification of a very complex situation. Because of this simplification, the analysis is preliminary. The most important assumptions of the analysis include the following: (1) Aggregation over space. The aggregation of consumptive use requests into just a few use locations for modeling may have masked localized uses that could have been assisted by the flow increases. (2) Aggregation over time. The aggregation over time to four time periods per year may have caused inaccuracies, for example, in computations of head for estimating power production from flow through the turbines, or of tds of stored water. (3) Flows. The analysis assumed that the 72-year period from 1906-1977 is a valid representation of pretreatment flows to be expected in the future (see BHL for some sensitivity analysis of this assumption), and that annual flow increases would be proportional to nearby annual mainstem flow. These assumptions may not hold. (4) Institutions. Current water allocation institutions

were assumed to remain unchanged. Institutional changes could significantly alter the disposition of both preincrease flows and flow increases (e.g., see BHL on the effect of allocating water by marginal economic value). (5) Salt concentrations. Salt (tds) loading and salt mixing within reservoirs were modeled in a simplistic way. Recent and ongoing research should be incorporated into a more complete analysis.[6] (6) Monetary values. Future real prices, especially fuel prices used to value hydroelectric energy, may be substantially different from recent ones. (7) Linearity. It was assumed that the hydrologic results from harvest of 334,600 acres apply to any subset of this area.

Conclusions

Modeling river basin water storage, loss, and routing is important in order to understand the disposition of streamflow increases. The timing of such increases, as well as the facilities and institutions that control their allocation, can play important roles in consumptive use of the increase. In the Colorado River Basin, it appears that--given current facilities and institutions--the flow increases would be largely unused consumptively.

Uses of the flow increases in both power production and salt dilution contributed in large measure to the total return of the vegetation treatment. While the value of instream uses will not outweigh the value of consumptive uses in all locations, instream uses should probably receive increased emphasis.

The economic results are largely indeterminant because of the sensitivity of net returns to the values assumed for water yields and the road construction requirements. Both the low and high value estimates used in this study are plausible given current knowledge. If watershed management decisions are to be analyzed from an economic efficiency perspective in the future, research is needed to more accurately estimate the values.

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Appendix

Hydropower

For each period, energy production in kilowatt hours (kWh) was computed as:

$$kWh_{ij} = H_{ij} * F_{ij} * Ef_j * C \qquad [1]$$

subject to

$$H_j \geq Hm_j \qquad [2]$$

$$kWh_{ij} \leq M_{ij} \qquad [3]$$

where

I		signifies time period
j		signifies hydroelectric dam
H	=	head in feet
F	=	flow in acre-feet
Ef	=	efficiency
Hm	=	minimum head for intake
M	=	maximum productive capacity (a function of turbine and generator capacities)
C	=	1.0253, a constant necessary to convert from acre – feet of flow to kWh (see Creager and Justin 1950).

Because hydropower plants can be brought on and off line easily, they are used when possible to replace power from the relatively expensive combustion turbine plants that supply additional power needed during peak demand times of the day. However, depending on power plant capacity and water releases from the dam, hydropower plants may run more continuously, thereby replacing baseload power typically produced by coal-fired plants.

The exact proportion of total power production at a hydropower plant that replaces power from combustion turbine plants depends on the proportion of the time that the hydropower plant is producing power (its production as a proportion of its capacity, or plant factor) and on how that power can be incorporated into the total power network. Information from the Western Area Power Administration suggests that a hydropower plant in the Colorado River Basin with a plant factor of 0.1 or less typically replaces only combination turbine power and that at greater plant factors coal-fired power is also replaced.

The high estimate of the hydropower value assumed that the value of the power was a function of the plant factor. For plant factors of less than or equal to 0.1, hydropower was assumed to replace power otherwise produced by combustion

turbine plants, and was valued at \$0.05 per kWh. For plant factors greater than 0.1, it was assumed that the hydropower associated with the 0.1 plant factor continued to replace combustion turbine power valued at \$0.05 per kWh, and that any additional hydropower replaced coal-fired power valued at \$0.018 per kWh, using the following weighted average computation:

$$\text{cost savings per kWh} = [(0.1*0.05) + (PF-0.1)*0.018]/PF \quad [4]$$

where PF indicates plant factor.

Total Dissolved Solids

The following relationships were used for total dissolved solid computations:

$$LBTDS_i = C * (RS_i + LBS_i) / (RW_i + LBIF_i) \quad [5]$$

where

$$RS_i = RW_i * STDS_i / C \quad [6]$$

$$STDS_i = C * (SS_{i-1} + UBS_i) / (SW_{i-1} + UBIF_i - E_i) \quad [7]$$

$$SS_i = SS_{i-1} + UBS_i - RS_i \quad [8]$$

$$SW_i = SW_{i-1} + UBIF_i - E_i - RW_i \quad [9]$$

given

$LBTDS_i$ = Lower Basin tds in period i (mg/l)

$STDS_i$ = tds of water stored in Powell and Mead in period i (mg/l)

RS_i = salt mass released from Mead reservoir in period i (tons)

RW_i = water released from Mead in period i (acre-feet)

LBS_i = salt mass entering Colorado River below Mead in period i (tons)

UBS_i = salt mass entering the Colorado River above Mead in period i (tons)

$LBIF_i$ = water inflow below Mead in period i (acre-feet)

$UBIF_i$ = water inflow to Powell plus inflow between Powell and Mead in period i (acre-feet)

SS_{i-1} = salt mass in storage in Powell and Mead at end of period i-1, beginning of period i (tons)

SW_{i-1} = water in storage in Powell and Mead at end of period i-1, beginning of period i (tons)

E_i = evaporation from Powell and Mead reservoirs in period i (acre-feet)

C = 735.374, a constant to convert from tons/acre – foot to mg/l.

Poster Papers

Krummholz Snowdrifts: Hydrologic Implications at a Colorado Treeline Site

Neil H. Berg[1]

Abstract--The water equivalent of snow contained in drifts downwind of krummholz vegetation at treeline on Niwot Ridge in the Colorado Front Range is estimated at 8,060 m^3 annually (1830 m^3 km^{-2} land area), or about 1% of the summer streamflow from a 191-ha alpine basin adjacent to Niwot Ridge. Most of this water would be lost to sublimation if the vegetation did not capture the snow. Much of the water becomes available after the date of peak discharge and contributes to late-season water supply and soil water recharge.

Blowing and drifting snow are important factors in alpine environments. The upper reaches of the subalpine zone become a deposition site for snow redistributed from the alpine. At the forest-alpine tundra ecotone, low-lying "krummholz" vegetation is the first impediment to snow-bearing winds. When snow is redistributed into drifts to the lee of krummholz tree islands, evaporation of wind-driven snow is reduced. As snow drifts melt, they become water sources to natural ecosystems and, particularly in their late-season residence after the primary snow cover has melted, for human use.

Niwot Ridge, an east-west trending spur on the east slope of the Colorado Front Range, 35 km northwest of Boulder, Colorado (40o3'20" N, 105o35' W), ranges in elevation from 3450 to 3800 m msl. At increasing elevations on Niwot Ridge, the closed crown forest gives way to stunted growth forms near the upper limit of tree growth as environmental conditions increase in severity. Severely deformed "krummholz" exist as isolated clumps of one or more trees. "Flag" krummholz grow where environmental conditions allow one or several vertical branches to survive above the protection of the winter snowpack; below the pack, growth is dense and mat-like. "Mat" krummholz exist at slightly higher elevations under extreme conditions that do not allow survival of the vertical leaders (Daly 1984). On Niwot Ridge *Picea engelmannii* (Engelmann spruce), with admixtures of *Abies lasiocarpa* (subalpine fir) and *Pinus flexilis* (limber pine), are the primary mat krummholz species. Krummholz occur over an elevation range of approximately 200 m and form a discontinuous catchment zone for blowing snow spanning the length of the Front Range (Ives and Hansen-Bristow 1983). This paper investigates the hydrologic role of krummholz snowdrifts and estimates the water equivalence and timing of release of snowmelt water from krummholz drifts on Niwot Ridge.

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Methods

To estimate the water equivalent of krummholz snow drifts, four steps were followed: (1) measure krummholz and drift geometries; (2) relate krummholz geometry to drift shape to determine individual snowdrift volumes; (3) quantify krummholz occurrence on Niwot Ridge; and (4) determine water equivalent.

Mat krummholz tend to be wedge-shaped with their apex height at the downwind edge (fig. 1). Width and height measurements were made at the apex of 171 randomly-selected mat krummholz during February and March, 1975, near the central portion of the Ridge. The length of the associated lee drifts and snow depth at the apex were also recorded. Techniques have been established to estimate drift volume, V. Tabler (1975:95) developed a snow retention model for sagebrush (Artemisia spp.) in which the drift forming behind an isolated plant approximates the shape of a half-cone, with length 10H (H= plant height), so that $V = 5.2H^3$.

The areal frequency of mat krummholz was determined by relating aerial photograph observations to a vegetation map of the Niwot Ridge forest-alpine tundra ecotone. Hansen-Bristow's (1981) vegetation map (1:10,000 scale) shows mat krummholz in a discontinuous band approximately 350 m wide over an area about 4.4 km^2 along the eastern two-thirds of Niwot Ridge. Since individual plants were not designated on this map, color aerial photographs (circa 1:15,000 scale) taken October 2, 1974 were analyzed with a zoom stereoscope capable of 10 X magnification. Individual trees were identified

Figure 1.--Schematic representation of a mat krummholz and lee snowdrift.

on the photograph and compared to their location on the map to determine growth form. Shadow length helped identify flagged trees.

Determination of snow water equivalent requires knowledge of the density of the drifts. Koerner (1969) found density in krummholz lee drifts on Niwot Ridge to vary generally between 0.40 g cm^{-3} and 0.47 g cm^{-3} and increase through time into the ablation period. These measurements, based on approximately 100 sampling points, are the basis for use of 0.45 g cm^{-3} as the value for snow density at the maximum accumulation date. Water equivalent for individual snowdrifts follows as the product of krummholz frequency, drift volume, and density. Total snow drift water equivalent for the basin is calculated by applying a probability density function developed from the field measurements of apex snow depth (taken to equal H) to the total krummholz population on the Ridge by means of the "half-cone" volume equation.

Results and Discussion

Measured tree heights (table 1) were within the ranges (0.5 to 2 m) measured by Koerner (1969), and noted by Hansen-Bristow (1981:38): "In this form the tree is dwarfed to a mat, usually no higher than 1.5 m, but up to 5 m long." Similarly, tree island lengths (table 1), averaging 3.75 m, were similar to those mapped by Koerner (1969). Mean tree width-to-height ratio was 2.4, and lee drift lengths averaged 8 times maximum drift depth (table 1). Relative variation of tree length was greater than for the other measured properties. The coefficient of variation ranged from 0.40 to 0.47 for the other four variables, but was 0.65 for tree length. The distribution of snow depths at the tree apex is not significantly different from normal (alpha = 0.05) (fig. 2).

Table 1.--Krummholz and lee snowdrift dimensions on Niwot Ridge, Colorado, February-March, 1975.

Variable	Mean (cm)	Median (cm)	S.D. (cm)	Max. (cm)	Min. (cm)	Sample size
Krummholz width	269	255	123	755	55	170
Krummholz height at apex	112	115	45	295	12	131
Krummholz length	375	320	245	2,000	60	171
Drift length	605	560	282	1,750	100	171
Drift depth at krummholz apex	76	75	34	168	8	171

Four thousand, six hundred and ninety mat krummholz (approximately 670 km^{-2}) were estimated as occurring within the Niwot Ridge forest-alpine tundra ecotone. The volume of snow in the associated lee drifts was estimated at 17900 m3, with a snow water equivalent of 8,060 m^3, or 1,830 m^3 km^{-2} (at snow density = 0.45 g cm^{-3}). To put this value into perspective, in 1974, a slightly above-average winter precipitation year on Niwot Ridge, peak daily discharge from a 191-ha alpine basin immediately south of the Ridge was 35,200 m^3 (Carroll 1974). Drift snow water equivalent therefore approximated one-quarter of the peak annual single-day streamflow, or about 0.8% of the mid-June through late-October streamflow.

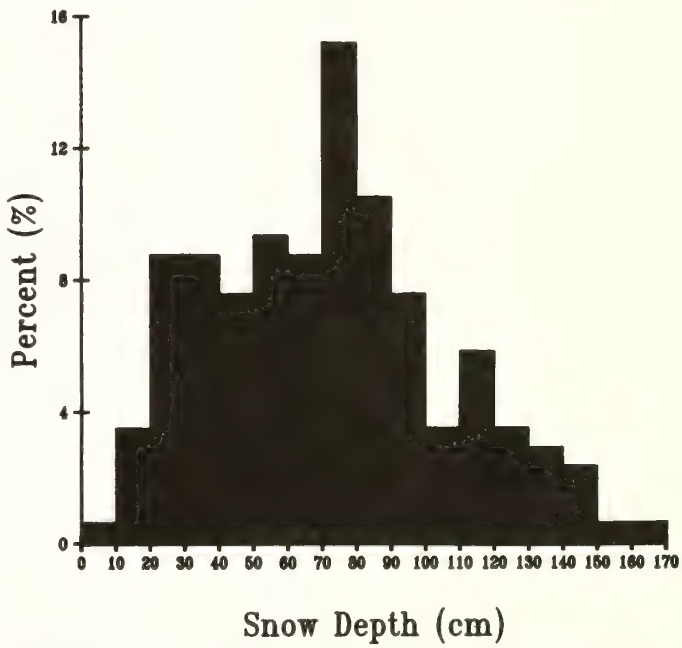

Figure 2.--Krummholz apex snow depths on Niwot Ridge, Colorado.

Error Assessment

The magnitude of errors associated with several components of this analysis needs explanation. Errors associated with the krummholz frequency estimate are probably the largest in this study. Even with the optical magnification available for the aerial photograph interpretation, trees less than 20 cm tall may not have been identified and the distinction between mat and flagged forms was not always completely reliable.

The half-cone equation (Tabler 1975) was formulated for an area with unidirectional winds, uniform terrain sloping less than 15%, sufficient snow for the drifts to reach equilibrium profiles, crown width approximately twice crown height, and drifts approximately 10H in length. These conditions were generally satisfied within the krummholz communities sampled on Niwot Ridge. In this application, apex snow depth is the effective crown height, since the top portion of the krummholz is sparsely foliated and relatively ineffectual as an aerodynamic barrier. On the average, measured tree width was slightly more than twice tree height and drift length was slightly less than 10 times snow depth at the apex. The importance of barrier height in determining lee drift volume is supported by numerous snow fence studies (Tabler 1986) and by the moderately high Pearson correlation coefficients for associations between drift length (a proxy for drift volume) and both krummholz height ($r= 0.82$) and apex snow depth ($r= 0.78$). The shape and porosity of krummholz and sagebrush differ; krummholz are wedge-shaped whereas sagebrush are spherical. Not enough is known about the magnitude of these variations to quantify the error.

Use of a constant value for snow density is a simplification. Snow deposited in the interstices of the vegetative mat, while relatively low in volume, is not accommodated, nor is the interaction between krummholz drifts and topographic snow traps. Snow firnification, drift erosion due to high velocity winds, variations in tree island aspect and the consequent variations in ablation rates due to differences in insolation are likewise not considered. These influences are essentially impossible to quantify on a basin scale. The calculations described here are a conservative "first approximation" of drift snow water equivalent.

Timing of Water Availability

Even if the actual water equivalent is twice the estimated amount, the total water contained in the drifts is relatively small when compared to typical streamflow volumes. The importance of this water is not primarily in its magnitude, but may be in the timing of its availability.

Estimation of the timing of water release from the drifts on Niwot Ridge has relied on two data sources: field measurements of several mat krummholz lee drifts made throughout the 1965 ablation period (Koerner 1969), and of a flag krummholz and terrain drifts during 1974 (Berg 1977).

Extrapolation of Koerner's data suggested drift disappearance by June 25, 1965. Extreme snowpack ablation rates occurred in 1965 (Rennick 1966), therefore the late-June meltout date was probably earlier than average. Even so, in an above-normal snowfall year, 1974, peak stream discharge occurred on June 24, suggesting that krummholz drifts may melt out after the stream flow peak. Casual observations over several years by Daly (per. comm. 1987) suggest, however, that mat krummholz drifts melt relatively quickly, and disappear probably only a few days after the date of peak stream discharge. This may be due to their relatively shallow depths. Drifts behind flag krummholz, on the other hand, can persist several weeks longer, often well into July. The 1974 measurements support this claim. Maximum depths at terrain drifts were greater than 3.8 m on April 17, 1974, a date when the maximum depth recorded at a nearby flag krummholz drift was 3.7 m. Snow over 1.5 m deep persisted at the terrain drifts as late as mid-July 1974, several weeks after the June 24 peak streamflow discharge in nearby Green Lakes Valley. Although measurements of the flag krummholz drift were not made in July, given the near equality of snow depths on April 17, it is reasonable to hypothesize that the flag krummholz drift had not completely melted in mid-July, 1974. The flag form of krummholz is generally larger than the mat form, so that deeper drifts form which take longer to melt. It may be that the optimal condition for both drift accumulation and melt delay occurs when krummholz, either flag or mat, are situated immediately upwind of terrain snow traps, as on ridge-terrace lines (Koerner 1969).

Alpine snowfields generally supply late season runoff to lowland areas, and the preliminary observations reported in this paper suggest that drifts associated with krummholz contribute to runoff even later than the average from alpine catchments. Although the quantity of water from the drifts is relatively small, about 1% of the summer streamflow from a 191-ha alpine basin adjacent to the study area (or one-quarter of the peak single day discharge), a 7-to-10 day delay in release of snowmelt water from the larger krummholz drifts adds to the importance of this water source in an otherwise "summer dry" lowland environment. Much of this water would be lost to sublimation if the vegetation did not accumulate snowdrifts.

Acknowledgements

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The Coon Creek Water Yield Augmentation Pilot Project

G. S. Bevenger and C. A. Troendle[1]

Abstract--Research in the Rocky Mountain subalpine zone has demonstrated that vegetative manipulation (primarily clearcutting) causes a net reduction in evapotranspirational losses, changes the aerodynamics and energy balance of the timber stand, and results in increased streamflow. Because the results of research on small watersheds has shown that water yield can be increased, and because forest management represents one of several options for manipulating water yield, the Coon Creek Water Yield Augmentation Pilot Project was initiated. The objective of the project is to apply state-of-the-art technology in water yield management on an operational timber sale. The project also will make possible large-scale testing and field verification of hydrologic prediction tools so commonly used in planning.

More than 70 years of watershed research throughout the United States, and specifically in the West, has provided the technology to substantially increase usable water from forested lands. The long-term intent of the Coon Creek project is to produce increased quantities of usable water in harmony with sound multiresource management of National Forest land. The Forest Service, Rocky Mountain Region, responded to a 1980 national initiative to augment water yield by proposing the Coon Creek Pilot Project to apply technology developed primarily at the Fraser Experimental Forest and elsewhere in the Rocky Mountain Region. A second objective is to evaluate, on a large scale, the reliability of state-of-the-art hydrologic predictive tools currently being used, such as the Subalpine Water Balance Model (Leaf and Brink 1973a, 1973b), WRENSS (Troendle and Leaf 1980a), and other locally developed models.

Coon Creek was selected as the project area primarily because the watershed in which it is located, the East Fork of the Encampment River, is a large, uncut and unroaded watershed of the size necessary for evaluating a commercially viable timber sale. The basin consists of two watersheds of comparable size, aspect, and timber types, which allows for a paired watershed study. The drainages are uniformly covered with commercially operable timber, and the drainage selected for treatment (Coon Creek) can be logged by conventional harvesting methods using standard silvicultural practices (patch clearcutting).

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Watershed Description

Coon Creek, the treatment watershed, is a 3,987-acre drainage located on the Hayden District of the Medicine Bow National Forest in Wyoming. It drains to the west at elevations ranging from 8,800 to 10,980 feet. Adjacent to Coon Creek is the Upper East Fork, the 2,252-acre control watershed. The Upper East Fork drains to the southwest at elevations ranging from 8,800 to 10,090 feet. Soils in both drainages are developing from alluvium and colluvium by weathering of igneous and metamorphic material. Soils generally vary between 20 and 60 inches in depth and are well drained. The soils are capable of absorbing water at rates in excess of snowmelt and normal rainfall intensities, so surface erosion is minimal.

The climate of the area is generally influenced by frontal systems and orographic storms during winter months, and by orographic and convectional storms during summer months. Mean yearly precipitation and mean yearly temperatures are estimated to be 40 inches and 34° F, respectively. Approximately 70% of the precipitation comes in the form of snow. Streamflow from May to September is directly and indirectly the result of snowmelt, and flow generation is mostly subsurface in nature. Estimated average annual water yield is 1.8 acre-feet per acre, with water quality generally good to excellent.

Forest cover consists of spruce-fir stands along stream courses, on north slopes, and at upper slope positions. Lodgepole pine grows on all low- and mid-elevation southerly or high-energy exposures. Alpine tundra is above timberline. Part of the area was extensively harvested for railroad ties in the early 1900s, but regrowth now completely occupies the site hydrologically.

Treatment and Measurement Methods

In 1982, 8-foot Cipoletti weirs were built on both East Fork and Coon Creek, and they are operated from April to October each year. To further assist the calibration process and to evaluate treatment effects, an extensive network of climatic instrumentation also was installed across the two watersheds in 1982 and 1983 (fig. 1). Climatic parameters being monitored include solar radiation, air temperature, relative humidity, and precipitation. Precipitation measurements include both rain and snow components. Included in the snow component measurement is a 600-point, random-walk snowcourse, which is surveyed around April 1 of each year. Survey data are used to estimate mean water equivalent in the snowpack for each watershed (all instrumentation and snowcourse locations are shown in fig. 1).

To date, 4 to 5 years of record have been collected, depending on the parameter: 4 years of flow record (1987 is the fifth year), 5 years of snowcourse record, and 4 years of temperature, precipitation, radiation, and humidity data. So far, the correlations between the watersheds appear quite good for all parameters.

Watershed Calibration

Average monthly precipitation is fairly well distributed throughout the year on both watersheds (fig. 2). Rain falls during the months of June through August, while snowfall dominates from September to May. There is a strong orographic effect between elevation and precipitation on Coon Creek, as is indexed by the relationship shown in figure 3. The orographic effect holds year round.

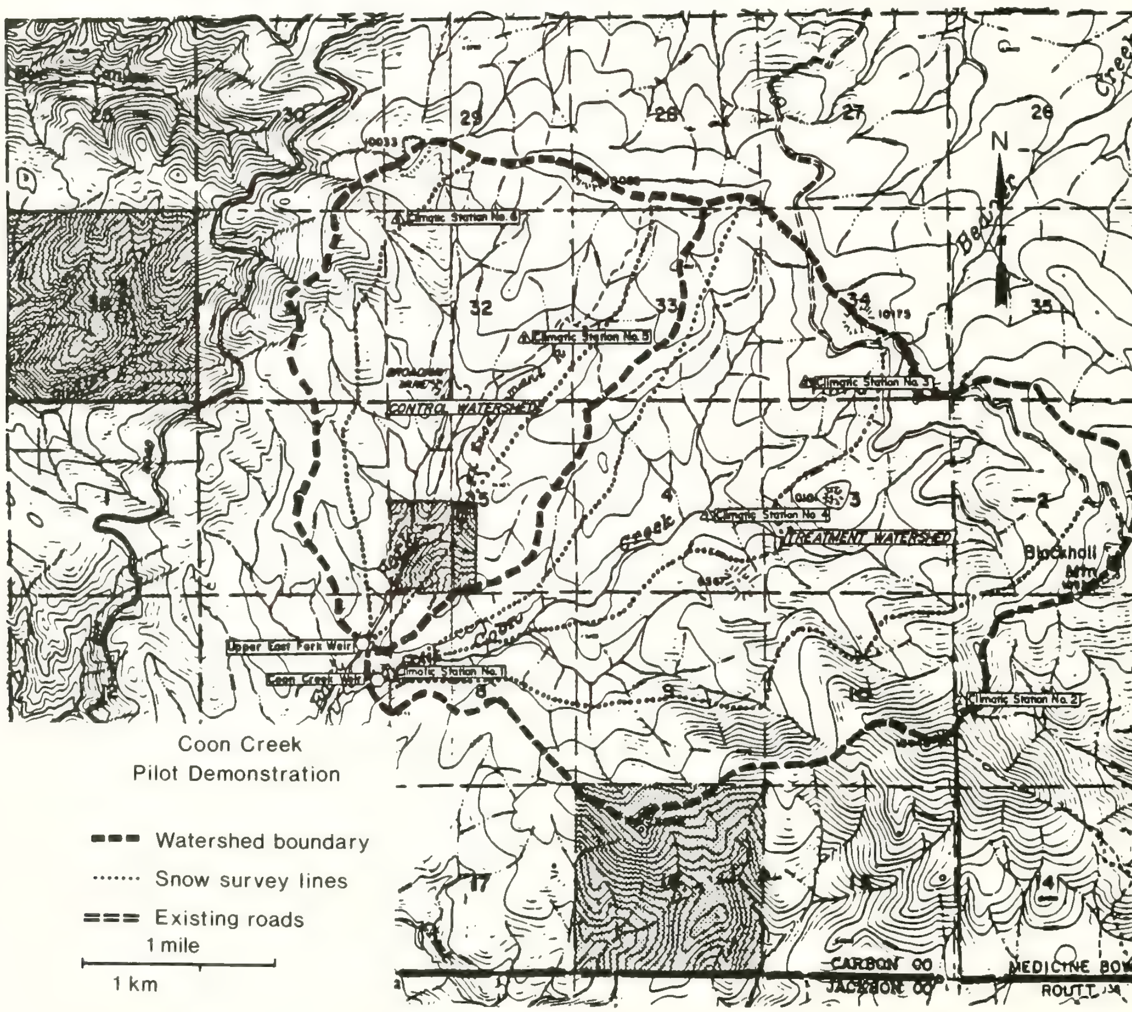

Figure 1.--Map of the Coon Creek and East Fork watersheds showing snow course, climatic station, and streamgage locations.

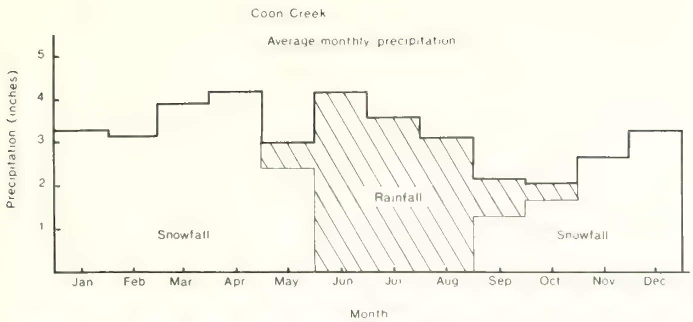

Figure 2.--Average monthly precipitation for the Coon Creek watershed.

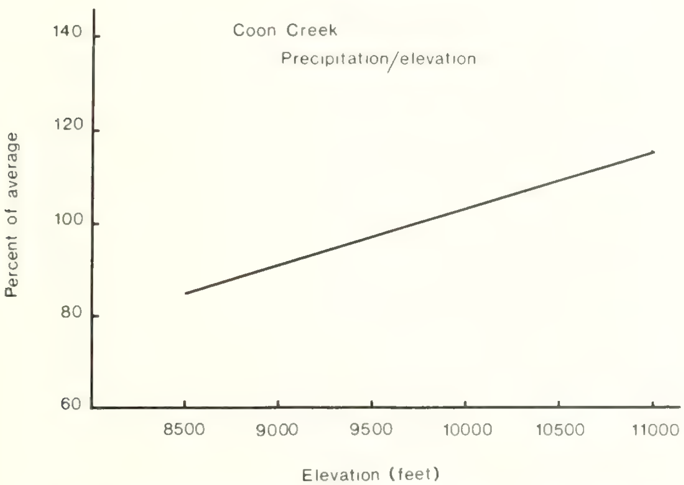

Figure 3.--Adjustment factor to be used to adjust average monthly watershed precipitation (fig. 2) for elevational effect.

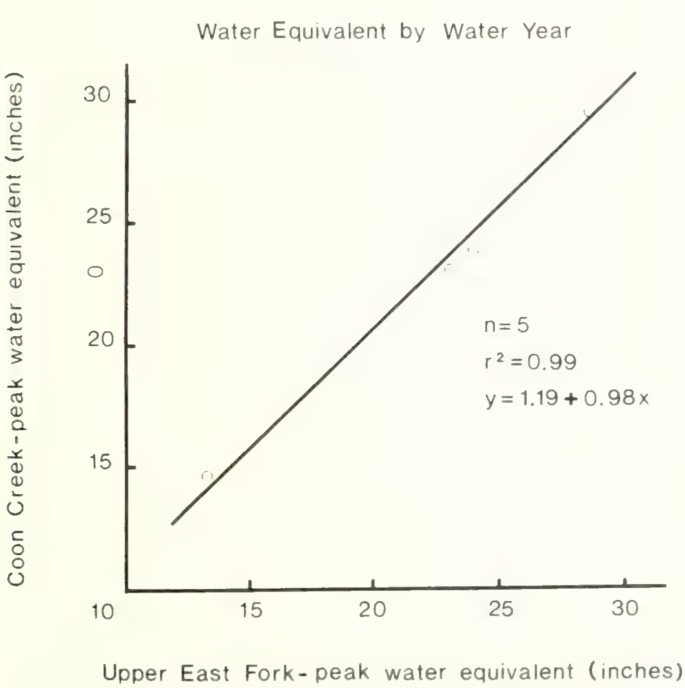

Figure 4.--The relationship between peak water equivalent on the Coon Creek and East Fork watersheds.

In addition to the climatic installations, permanently marked random walk snowcourses also are located in each watershed. Approximately 200 stations are located in the East Fork drainage and 400 in the Coon Creek drainage (fig. 1). Although the 5 years of existing data demonstrate considerable variability among stations, snowpack accumulation increases significantly with elevation on all snowcourse transects. Figure 4 presents the relationship of mean peak water equivalent on the East Fork and Coon Creek watersheds. The agreement is quite strong: an r^2 of 0.99 with a standard error of 0.38 inch. Water equivalent on Coon Creek ranged from 15 to 30 inches during the 5 years of record, or from two-thirds of normal to a one in 40-year extreme.

The average annual hydrographs for Upper East Fork and Coon Creek for the years 1983 to 1986 show a strong correlation (fig. 5). The majority of flow occurs in May and June, and is the result of melting snowpack. Analysis of the first 4 years of record indicates that 83% of the variation in flow from Coon Creek and 95% of the variation on East Fork can be explained by mean peak water equivalent (PWE) in the snowpack on April 1 (fig. 4). Although the correlations are higher than usually observed elsewhere, the relationship is typical of that for the subalpine forest (Troendle and Leaf 1980; Troendle and King 1985, 1987).

The correlation between annual flows from Upper East Fork and Coon Creek, like peak water equivalent, also is quite good (fig. 6). The first 4 years of record were very wet years, with flow level very high and having very little variation from year to year. However, 1987 appears to be a dry year (60% of normal), and the estimated flow level is quite low (estimate is measured flow for April, May, and June for both watersheds). This low value provides the range needed in order to have confidence in the application of the calibration relationship. The range in return intervals for the calibration period (5 years) goes from one in 0.60 year to one in 40 years.

In addition to annual flow, we also evaluated the character and relationship of storm discharge from the two watersheds. Thirty-one storms (rain only) occurred during the months of July through September of 1983 and 1984. Only a minimal portion of the precipitation was returned as stormflow or quickflow (using definition of Hewlett and Hibbert 1967). The individual rainfall events ranged from 0.01 to 0.78 inch, while stormflow response varied from 0.001 to 0.019 inch. The average storm size was 0.31 inch, while the average response was 0.01 inch, or 3% of the precipitation returned as flow. Subsequent analysis indicated no correlation ($r^2 = 0.00002$) between storm size and storm response. The lack of response is not surprising, since summer precipitation does not appear to be well correlated with flow in the subalpine environment (Troendle and Leaf 1980; Troendle and King 1985, 1987). What storm response that did occur probably was the result of direct channel interception of the precipitation.

The 5 years of record currently available indicate that precipitation, snowpack accumulation, and flow all are well correlated between the watersheds, and the proposed harvest

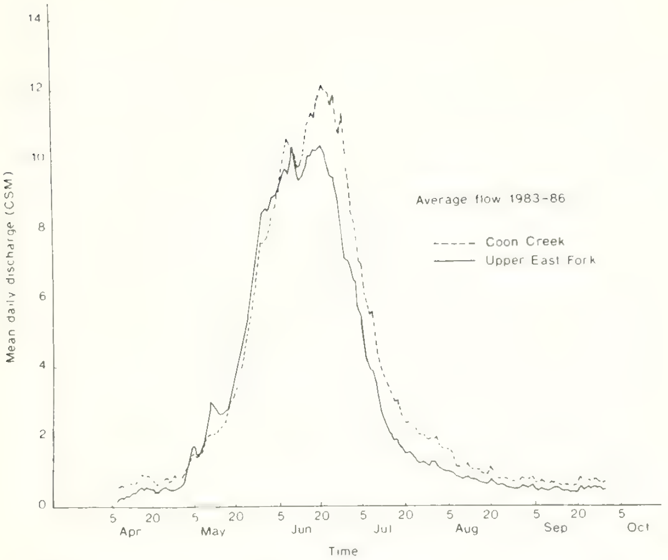

Figure 5.--Average annual hydrographs (1983 to 1986) for Coon Creek and Upper East Fork drainages.

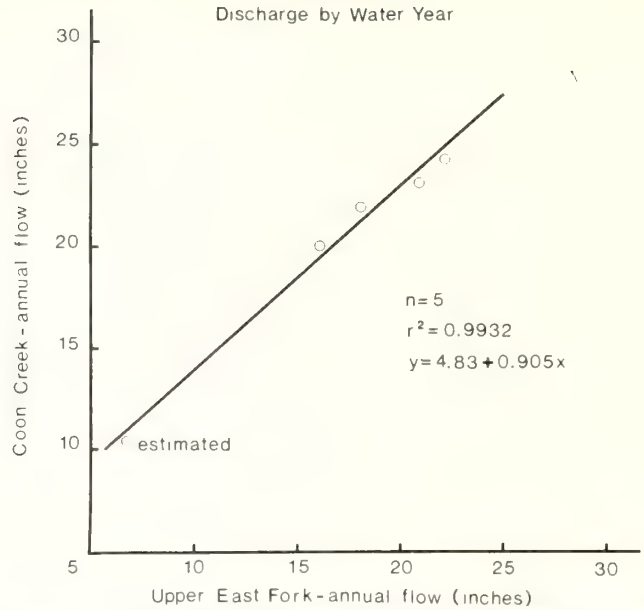

Figure 6.--The relationship between flow on Coon Creek and Upper East Fork for the first 5 years of calibration.

can proceed as planned, beginning in 1989. We anticipate a several-inch increase in flow, but a change as small as 1 inch will be detectable.

Approximately 27% of the Coon Creek watershed will be harvested in small irregular clearcuts ranging in size from a few acres to 13 acres (fig. 7). No riparian areas will be harvested, and the proposed practice will meet all requirements of the existing forest plan. Current plans are to monitor the watershed for several years following harvest to determine the response, and how accurately we were able to predict it.

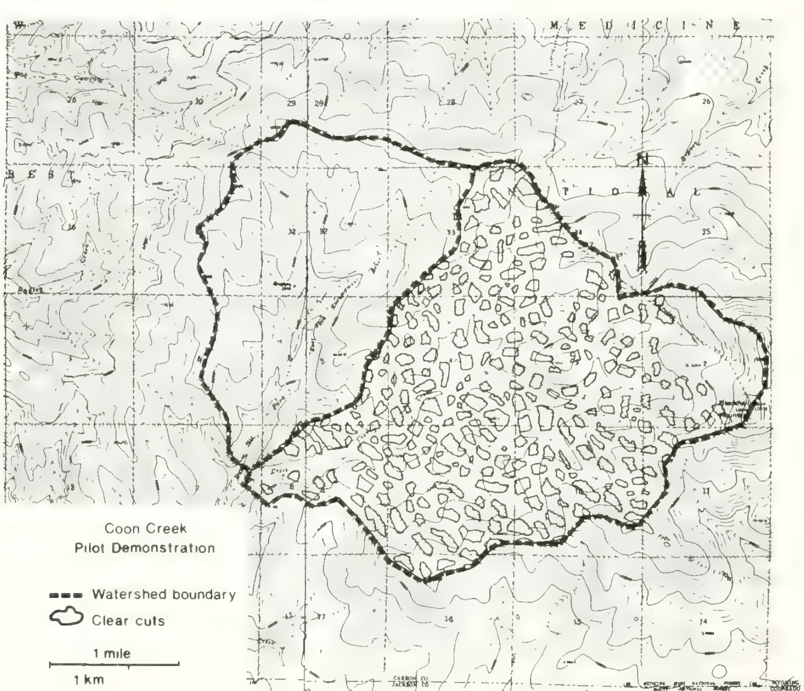

Figure 7.--Proposed sale layout, Coon Creek watershed.

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Studies on the Resting Site Ecology of Marten in the Central Rocky Mountains

Steven W. Buskirk, Henry J. Harlow, and Steven C. Forrest[1]

Abstract--Studies on the resting site ecology of marten *(Martes americana)* in the central Rocky Mountains are described. Body temperature dynamics, ambient temperature-specific metabolic rates, ecological characteristics of resting sites and the relationship between resting site use and environmental factors are being studied. These studies will provide insight into the basis for the old-growth association of marten.

The marten *(Martes americana)* has been selected as a management indicator species by several national forests of the intermountain West. One ecological trait makes this designation particularly appropriate; marten are among the most habitat-specialized of North American mammals (fig. 1), being largely restricted to conifer-dominated forests and attaining their highest densities in late successional stands (Allen 1984). Harris (1984) considered marten to be among the most climax-dependent of North American forest mammals.

What are the bases of the old-growth dependency of marten? Do marten require old-growth because of the types of prey that are found there, because of favorable access to prey, because of the availability of predator-avoidance habitats to marten themselves, or because of the availability of features that are important as thermal cover? Our studies are directed at understanding how marten may use specific forest habitat features to thermoregulate in winter.

A number of resting sites used by free-ranging marten have been described (table 1). These sites range from the forest canopy to beneath the soil surface. Particularly in winter, resting sites are often associated with coarse woody debris, including logs and stumps, below the snow surface (Spencer 1981, Steventon and Major 1982, Martin and Barrett 1983). In summer, marten usually rest in sites above the soil surface, often in the canopy layer (Burnett 1981, Martin and Barrett 1983). However, it is not clear whether these sites were selected on the basis of convenience, or other factors. It is an objective of our studies to monitor physiological and microenvironmental in order to help discern this relationship.

Although several mustelid species have received attention from physiologists because of their long, thin shapes and consequently high surface area/mass ratios (e.g. Brown and Lasiewski 1972, Iverson 1972), few metabolic or energetic studies of marten have been undertaken. Worthen and Kilgore (1981) found that the lower critical temperature ($\underline{T}_{lc}$, the ambient temperature [$\underline{T}_a$] below which an animal must shiver to maintain its body core temperature [$\underline{T}_b$]) of marten was 29° C, which is higher than the $\underline{T}_a$ experienced by free-ranging marten for most, if not all of the year. In an associated study on metabolic responses by marten to low $\underline{T}_a$s, we reinvestigated this relationship and calculated a considerably lower value of $\underline{T}_{lc}$ of 16° C. Even with this lower (and more adaptive) value, the thermal relationship of the marten to its environment is a tenuous one. During winter, when marten must maintain $\underline{T}_b$-$\underline{T}_a$ gradients of up to 80° C, and $\underline{T}_a$s are 11-57° C below our calculated $\underline{T}_{lc}$, energetic costs of foraging and of resting above the snow surface must be very high. These postulated energy losses caused us to suspect that marten would be highly selective in their choice of resting sites during winter, and would exhibit patterns of resting site use that were keyed to weather variables.

Study Area and Methods

Field studies have been carried out in the Snowy Range region of the Medicine Bow National Forest, in southeastern Wyoming. The approximately 108-km^2 study area ranges from 2,500 m to 3,300 m in elevation and includes two forest zones, one dominated by Engelmann spruce *(Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)*, the other by lodgepole pine *(Pinus contorta)*. Spruce-fir stands contain large, old trees, hold large amounts of large dead woody material, are unevenaged and generally meet criteria (Franklin et al. 1981) for old-growth forest. The area is used intensively for recreation, with

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Table 1. Resting sites reported to be used by American marten, by type.

CITATION AND SEASON OF STUDY[1]	Study Location	RESTING SITE CATEGORY																		
		Sites > 2m Above Ground				Sites < 2m Above Ground														
		Canopy Layer				Coarse Woody Debris							Other							
		Crown	Limb or branch	Witches broom/dwarf mistletoe	Squirrel nest	Top of broken snag	High tree/snag cavity	Low tree/snag cavity	In or under stump	Inside downed log	Under downed log	Slash pile	Talus or rock pile	Squirrel midden	Animal burrow	Animal surface nest	Man-made structure	Unknown surface (subnivean)	Other	Total
Burnett (1981)	MT																			
Spring, Summer, Fall			11		2		3	1				1					1		1	20
Winter			8	1	2							4			1					16
Buskirk (1984)	AK																			
Spring, Summer, Fall																				
Winter					3									28	6					37
Campbell (1979)	WY																			
Spring, Summer, Fall				5			14					4								23
Winter																				
Hargis and McCullough (1984)	CA																			
Spring, Summer, Fall																				
Winter											2						1			3
Hauptman (1979)	WY																			
Spring, Summer, Fall				1			8/7[2]			2[2]			1							12
Winter											16									16
Marshall (1942)	ID																			
Spring, Summer, Fall																				
Winter							1		2		13									16
Martin and Barrett (1983)	CA																			
Spring, Summer, Fall		16				21		3	46		19		1						18	124
Winter		6					36	3	5		41		2					24		117
Masters (1980)	NY																			
Spring, Summer, Fall			3				1	1												5
Winter																				
Mech and Rogers (1977)	MN																			
Spring, Summer, Fall			1										4	2						7
Winter													2		3					5
Newby (1951)	WA																			
Spring, Summer, Fall																				
Winter							X		X			X								
Simon (1980)	CA																			
Spring, Summer, Fall		5	1			26		1[2]										3		36
Winter																				
Spencer (1981)	CA																			
Spring, Summer, Fall		4	8	6		3	12	4	5		3		3			4				52
Winter								7	7		13	6	2			1	7			43
Spencer (in press)	WA																			
Spring, Summer, Fall																				
Winter															2			9		11
Steventon and Major (1982)	ME																			
Spring, Summer, Fall																				
Winter		1						2	19			3								25
Wynne and Sherburne (1984)	ME																			
Spring, Summer, Fall		6/2[2]		18		3/2[2]	4[2]												8	39
Winter																				

[1] Spring, Summer, Fall considered snow free. Daytime temperatures generally over 0° C.

[2] Natal (maternal) den.

X Occurs in category.

about 140 summer cabins and a public ski area. More detailed descriptions of the study area are provided by Oosting and Reed (1952), Billings (1969), and Fahey (1983).

Marten were captured in baited live traps using oil of anise as a lure. Traps were placed in protected sites and were provided with floors of closed-cell polyurethane foam. Trapping was conducted for periods of 2-10 nights on an intermittent basis from November 1985 to February 1986 and from November 1986 to January 1987. The total effort involved 496 trap-nights at an estimated density of 1.8 traps/km snowmobile trail. No injury or mortality to marten resulted from trapping operations. Captured animals were transported to the University of Wyoming. Under ketamine hydrochloride anesthesia, a precalibrated T_b-sensitive transmitter (Minimitter Model L) was surgically inserted into the peritoneal cavity and sutured to the midventral abdominal wall. A radiocollar (AVM Instrument Co.) was affixed to each animal. After recovery, each animal was released at the capture site.

Radio tracking has been conducted by snowmachine and on foot during daylight hours. When marten have been found resting, the resting site has been marked and a recording device left within 15 m of the site to sample and record transmissions from the radio implants. Each recording device consists of a transistor receiver with crystals matched to the frequencies of the temperature implants, a solid state timing device with controls for setting the duration of the signals recorded and the intervals between between readings, and an inexpensive cassette tape deck, all powered by cold resistant lithium batteries. Tapes of transmitted clicks have been converted to T_b manually using calibration curves. Standard weather data was recorded by four climate stations within the study area. In addition, temperature data were gathered for 7 sites above and within the snow layer of an old-growth spruce-fir stand.

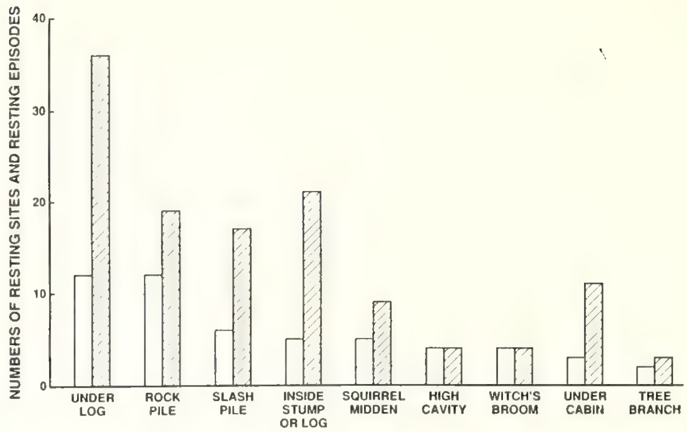

Figure 2.--Numbers of resting sites (solid) and numbers of resting episodes (shaded) used by marten in the Snowy Range of southeastern Wyoming, winters of 1985-86 and 1986-87, by type.

Results

Body temperature dynamics, patterns of resting site use and activity patterns of eight marten (six males, two females) were studied over two winter field seasons. No radio collars and only two temperature implants failed prematurely. Over 1,300 measurements of T_b were made during 93 resting episodes. These data are still being analyzed; but it is apparent that marten exhibited considerable daily lability of T_b. Depression of observed T_bs below active levels did not exceed 5.1° C. Such a hypothermic state would produce a deep sleep, but not the torporous condition typical of true hibernators (Swan 1974). We are currently looking at the relationships among weather factors, duration of resting episodes and depth of T_b depression during rest.

Fifty-seven resting sites used by marten during winter were characterized. Marten rested in sites that were generally associated with coarse woody debris or rockfields (fig. 2). The highest rates of reuse were observed in sites that were associated with logs or stumps or were beneath cabins (fig 2). We are currently looking at the distribution of winter resting sites in relation to mapped stand types and major topographic features.

	Arctic Tundra	Alpine Tundra	Boreal Forest	Northern Hardwood Conifer Forest	Aspen Parkland	Montane Woodland	Pacific Rain Forest	Eastern Deciduous Forest	Grasslands	Oak Savannah	Northern Desert Scrub	Southern Desert Scrub	Mesquite Grassland	Pinyon Juniper	Chaparral Oak Woodland	Southern Evergreen	Mexican Pine and Pine Oak	Farmlands Croplands
Canis latrans		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•
C. rufus							•		•							•		
C. lupus	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	
Alopex lagopus	•																	
Vulpes vulpes	•	•	•	•	•	•	•	•	•	•	•			•	•	•		•
V. macrotis						•			•		•	•	•	•	•			
V. velox						•			•		•			•				
Urocyon cinereoargenteus				•		•	•	•	•	•	•	•	•	•	•	•	•	•
Ursus americanus			•	•	•	•	•	•		•	•	•	•	•	•	•	•	
U. arctos	•	•	•	•	•	•	•		•	•	•	•		•	•		•	
Bassariscus astutus						•	•			•	•	•	•	•	•	•	•	
Procyon lotor			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Martes americana			•	•		•	•											
M. pennanti			•	•		•	•											
Mustela erminea	•	•	•	•	•	•	•	•	•	•	•			•				•
M. nivalis	•	•	•	•	•			•	•	•								
M. frenata		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
M. nigripes									•		•		•	•				
Gulo gulo	•	•	•	•	•		•											
Taxidea taxus		•		•		•		•	•	•	•	•	•	•	•		•	•
Spilogale putorius								•	•	•						•		•
S. gracilis						•	•		•		•	•	•	•	•		•	•
Mephitis mephitis			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Felis concolor			•	•	•	•	•	•		•	•	•	•	•	•	•	•	
F. lynx		•	•	•		•												
F. rufus			•	•		•	•	•	•	•	•	•	•	•	•	•	•	•

Figure 1.--Distribution of North American Carnivora with ranges mostly north of Mexico in major biomes mapped by Aldrich (1963). Biomes in which a species has occurred commonly in historic times are dotted. Mammal classification follows Jones et al. (1982).

Discussion

The close association of marten with old-growth stands, combined with the high monetary values of these stands and their long rotation times (Oosting and Reed 1952) cause us to anticipate that the marten is likely to be a sensitive species in management of subalpine forests of the central Rockies during the next two decades. As fragmentation of old-growth forests continues, managers will be increasingly pressed to document the responses of marten to this habitat alteration. An understanding of how management practices influence the habitat mosaic provided to marten, including their use of and dispersal through various cover types, and use of corridors between critical habitat components will be necessary. Ultimately, habitat requirements that provide for the genetic and demographic viability of populations through will have to be described.

Our research addresses key components of the functional importance of old-growth features to marten thermoregulatory behavior. How marten thermoregulate by modulating T_b, how they use protected microenvironments to minimize heat loss, and how their use of microhabitats varies with weather may go far to explain why marten are so closely associated with old-growth, during winter. A solid understanding of the criti-

cal habitat components of this species will provide a more meaningful definition of what marten ecological features marten may indicate, and how marten may be more effectively managed in forest ecosystems in the future.

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Control of Dwarf Mistletoes with a Plant Growth Regulator

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Abstract--This paper summarizes test results of ethephon, an ethylene-releasing plant growth regulator, as a control for two dwarf mistletoes: *Arceuthobium americanum* on *Pinus contorta* and *A. vaginatum* subsp. *cryptopodum* on *P. ponderosa* in Colorado. Ethephon at 2,500 ppm with a surfactant was tested using three application methods: a bottle sprayer, a backpack mistblower, and a hydraulic sprayer. Dwarf mistletoe shoot abscission rates of 74% to 100% were consistently achieved using these ground application methods. Mistletoe seed dispersal the year after ethephon application was much less in the treated plots than in the nontreated control plots. An evaluation of aerial application methods is in progress.

Dwarf mistletoes, *Arceuthobium* spp., are parasitic seed plants. They are regarded as one of the most damaging disease agents of conifers in the United States. An estimated 418 million cubic feet of wood fiber is lost annually to these pathogens either through growth reduction or tree mortality (Drummond 1982). These obligate parasites also lower wood quality and reduce cone and seed production of infected trees.

It has long been felt that an effective, safe, and economical chemical control of dwarf mistletoes would significantly reduce the impact of a major forest disease, especially in high-value stands, recreational areas, seed orchards, and ornamental plantings around homes, cabins, and business establishments.

Much successful research has been done on silvicultural control of dwarf mistletoes. But until recently, no effective chemical control had been found. Livingston and Brenner (1983) tested ethephon on *A. pusillum* on black spruce, *Picea mariana*, and consistently achieved 74 to 100 percent abscission of dwarf mistletoe shoots. They predict that abscission of aerial dwarf mistletoe shoots can prevent the spread of this disease in treated black spruce for at least 2 years.

Ethephon is quite safe and is routinely used on food crops to promote the abscission of leaves and fruits (DeWilde 1971). As ethephon is absorbed into plant tissues, ethylene is released, causing susceptible plant parts to abscise. There are no toxic by-products when the compound breaks down. Ethylene also exists naturally in conifers and is presumably responsible for natural abscission of aging dwarf mistletoe shoots. Based on these facts and the encouraging results achieved in the eastern dwarf mistletoe study (Livingston et al. 1985), we decided to test ethephon on two other extremely damaging dwarf mistletoe species in the western United States: *A. americanum* on lodgepole pine and *A. vaginatum* subsp. *cryptopodum* on ponderosa pine.

Methods

Studies of ethephon control of *A. americanum* on lodgepole pine were conducted in Colorado on the Fraser Experimental Forest from 1983 to 1986 and at Cutthroat Bay in the Arapaho National Recreation Area in 1985. We also set up a preliminary study on *A. vaginatum*-infected ponderosa pine near Meeker Park, Colorado, in the Roosevelt National Forest in 1985. Ethylene-releasing agents containing ethephon, Florel® and Ethrel,® at 2,500 ppm in water with a surfactant were tested on *A. americanum*, using three ground application methods: a bottle sprayer, a backpack mistblower, and a hydraulic sprayer. A bottle sprayer was used to apply ethephon, at the same concentration, to *A. vaginatum*. Two methods of evaluating the effectiveness of the treatments were used: the 6-Class Dwarf Mistletoe Rating (DMR) (Hawksworth 1977) and the Total Dwarf Mistletoe Area Rating (square inches) (Nicholls et al. 1987). Also, aerial applications of 1,200 and 2,400 ppm ethephon with surfactants were tested in 1986. Details of all 1983 to 1986 application and

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evaluation methods are in the paper by Nicholls et al. (1987) or in progress reports on file at the North Central Forest Experiment Station. This paper summarizes those results.

Results and Discussion

Dwarf mistletoe shoot area abscission rates of 74 to 100 percent (table 1) and DMR abscission rates of 30 to 100 percent (table 2) were achieved using ground application methods. Most shoot abscission occurred within 2 to 5 weeks after ethephon was applied (fig. 1). Mistletoe seed dispersal the year after ethephon application was significantly less in treated plots than in nontreated control plots. The bottle sprayer worked well for treating individual infections; the backpack mistblower worked well for trees 10 to 15 ft. tall; and the hydraulic sprayer was useful for trees up to 55 ft. tall. Some foliage turned brown on lodgepole pine and ground juniper (*Juniperus communis* subsp. *alpina*) when the hydraulic sprayer was used. This was probably due to the increased volume of ethephon solution that was applied with the hydraulic sprayer. Approximately 1 gallon of solution per tree was applied with the hydraulic sprayer; 0.4 gallon per tree was applied with the mistblower. However, the next year's buds and foliage developed normally.

Ethephon does not destroy the parasite's endophytic system in the host tissue. Therefore, new shoots began developing on some infections 1 to 2 years after treatment (fig. 2), and some shoots produced a few seeds 3 years after treatment. However, it will take time for the parasite to replace the large masses of mature shoots and seed that abscised after treatment. Therefore, we expect seed production and dissemination to be greatly reduced during this period. Because *A. americanum* and *A. vaginatum* have approximately 6 to 7-year life cycles, we feel that ethephon control will prevent or reduce significant spread and infection of dwarf mistletoe for up to 4 years and, perhaps, longer.

Table 1.--Percent reduction of Arceuthobium americanum and A. vaginatum female and male shoot area caused by 2,500 ppm ethephon compared to control treatments (N = 652 individual infections), Colorado, 1983-1985.

Study area	Treatment	% Total shoot area reduction Female	Male
A. americanum			
Sage (1983)	Ethephon/surfactant	89	95
	Ethephon/surfactant/DMSO1	74	100
	Control water/surfactant	4	9
Fool (1983)	Ethephon/surfactant	93	100
	Control water/surfactant	10	0
Gage (1984)	Ethephon/surfactant	97	99
	Control water	62	55
Headquarters (1985)	Ethephon/surfactant	97	100
	Control water	0	5
Cutthroat Bay (1985)	Ethephon/surfactant	78	87
	Control	0	0
A. vaginatum		(female and male combined)	
Meeker Park (1985)	Ethephon/surfactant	78	
	Control	0	

1DMSO = Dimethyl Sulfoxide

Table 2.--Percent 6-class Dwarf Mistletoe Rating (DMR) reduction of Arceuthobium americanum on lodgepole pine caused by 2,500 ppm ethephon compared to control treatments (N = 102 individual trees), Arapaho National Forest, Colorado, 1985.

Study area	Treatment	% DMR reduction
Cutthroat Bay		
Overstory trees	Ethephon/surfactant	30
	Control	0
Understory trees	Ethephon/surfactant	81
	Control	0
Fraser Experimental Forest		
Overstory trees (Area 1)	Ethephon/surfactant	70
	Control	0
Overstory trees (Area 2)	Ethephon/surfactant	90
	Control water	0
Understory trees (Area 2)	Ethephon/surfactant	100
	Control water	0

Aerial application of ethephon is currently being evaluated. This method may be useful in large stands of high recreational-value with understory regeneration. By controlling dwarf mistletoe in overstory trees, it may be possible to protect the understory trees from infection until they reach a size where dwarf mistletoe impact is less serious.

Mistletoe shoot abscission was not observed after the 1986 aerial application of ethephon. Although it is possible that the evaluation methods were not sensitive enough to measure effects, a more likely explanation is that not enough ethephon was applied to the plots to be absorbed by the mistletoe plants. The 10 gallons per acre applied in this study is much lower than the volumes applied during the successful ground applications: approximately 200 to 240 gallons per acre in the mistblower and hydraulic sprayer studies.

Conclusion

An effective, safe, and economical control of dwarf mistletoes would significantly reduce the impact of a major forest disease, especially in high-value stands. It would also provide forest managers with another control option to use in conjunction with silvicultural control methods.

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Figure 1. Ethephon control of *Arceuthobium americanum* on lodgepole pine: Presence of aerial shoots before and 5 weeks after ethephon was applied with a hand-held bottle sprayer, Fraser Experimental Forest, Colorado.

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Figure 2. Ethephon control of *Arceuthobium americanum* on lodgepole pine: Presence of aerial shoots before and 3 years after ethephon was applied with a hand-held bottle sprayer, Fraser Experimental Forest, Colorado.

Effect of Management on Nutrient Dynamics in Southwestern Pinyon Juniper Woodlands

L. F. DeBano and J. M. Klopatek[1]

Abstract--Pinyon and juniper trees cycle nutrients producing a mosaic nutrient distribution that is vulnerable to range improvement, grazing, and fuelwood harvesting activities. Prescribed fire releases small amounts of available nutrients, but also volatilizes large quantities. These impacts on nutrient cycling may affect long term productivity of pinyon juniper woodlands.

Pinyon juniper woodlands occupy 62 to 79 million acres in the western United States (Arnold et al. 1964) and about 15 million acres in Arizona and New Mexico (Springfield 1976). These woodlands, which occur in the transition zone between semiarid vegetation (chaparral, desert shrub or grasslands) and coniferous forests, are characterized by a mosaic of pinyon and juniper trees; interspace areas are occupied by sparse to dense herbaceous and shrubby vegetation.

Pinyon juniper stands are found on a wide variety of parent materials; soils vary in texture from stony, cobbley, and gravelly sandy loams to clay loams and clay, and vary in depth from shallow to deep (Aldon and Brown 1971, Pieper 1977, Springfield 1976). In pinyon juniper woodlands a soil nutrient mosaic pattern develops where carbon, nitrogen (N), and available phosphorus (P) are concentrated in the upper soil layers under the tree canopy. This pattern reflects the accumulation of litter by different plant species (Barth 1980, Charley and West 1975, Everett et al. 1986, Lyons and Gifford 1980, Klopatek 1987). Tree growth rates vary widely between sites in close proximity to one another. Since pinyon juniper woodlands occur in different climatic regimes, and on a wide variety of soil types, these variable growth rates suggest nutrient limitations may exist similar to those found in other forest ecosystems. Although N is usually considered the most limiting nutrient in forest ecosystems (Maars et al. 1983), it appears P and potassium (K) may also be limiting (Barrow 1980, Bunderson et al. 1985).

Past management has emphasized tree removal for range forage improvement, but recently interest has increased in harvesting pinyon and juniper trees for fuelwood. Prescribed fire has been used extensively during both range improvement and slash disposal after fuelwood harvesting. Intensive tree removal and prescribed fire, coupled with continued use for grazing, is expected to alter naturally occurring nutrient cycling processes in these woodlands and thereby affect long term interrelationships among site productivity, succession, and tree growth (Miller at al. 1981, Young and Evans 1981). This paper presents information on distribution of nutrients and their cycling in pinyon juniper woodlands, and assesses the effect of different management strategies.

Nutrient Cycling and Distribution

Pinyon and juniper trees cycle nutrients both horizontally (Tiedemann 1987) and vertically (DeBano et al. 1987). Tree roots penetrate into interspace soils between tree canopies where they absorb nutrients and incorporate them into tree biomass. A large portion of the nutrients captured from interspaces are deposited on the soil surface under trees during leaf fall, where they are released in an available form by decomposition, thereby enriching the upper soil layers. Trees also translocate nutrients vertically to the soil surface from deeper in the soil profile by a similar process. The quantity of nutrients cycled by trees varies considerably from one locality to another, depending upon land use, climate, soil, and tree density and size.

Published information on nutrient patterns in pinyon juniper woodlands clearly portrays strong vertical and horizontal distribution patterns developing from the above described nutrient cycling regime. The most important vertical compartments are: above ground biomass, litter, and soil nutrients. Nutrients are also distributed and exchanged horizontally between trees and interspaces, resulting in larger amounts of

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nutrients being present in the living biomass and litter trees compared to interspaces. The quantities of nutrients stored in soils under tree canopies has been reported by some authors to be greater than in interspaces (Everett et al. 1987, Tiedemann 1987), while in other cases no significant differences could be detected (DeBano et al. 1987). Information presented in the literature on N, P, and K were used to develop a model portraying vertical nutrient distribution patterns under trees and in associated interspaces for a typical pinyon juniper ecosystem (table 1). Data on N presented in table 1 for a pinyon juniper ecosystem was taken from Tiedemann (1987). Distributions of P and K were taken from DeBano et al. (1987), where soils data for the 0 3.8 cm depth was extrapolated linearly to 60 cm. Important features of the vertical distribution pattern are: (1) a small percentage of the total nutrient pool resides in plant biomass and litter, and (2) the three nutrients differed in the proportion of a nutrient stored in living biomass and litter. For example, under tree canopies higher proportions of N are present in litter and above ground biomass compared to P and K. About 98 percent of total P in the tree ecosystem is contained in soil, compared to 93 percent for K, and 82 percent for N. Horizontally, N, P, and K are concentrated in a mosaic pattern corresponding to litter and canopy distribution. Although total N, P, and K in the soil may or may not differ significantly beneath tree canopies and interspaces, more total N, P, and K accumulates in live tree boles, stems, and leaves and in litter under tree canopies than in interspace vegetation (DeBano et al. 1987).

Nutrient Availability

Available and total nutrients are delicately balanced because only a small percent of the total nutrient pool is in a readily available form. Vertical and horizontal distribution patterns of available and total nutrients are similar. Horizontal patterns of nitrate N and ammonia N are influenced by tree canopy distribution, with higher concentrations of ammonia N being found in the surface soil under tree canopies compared to interspaces (DeBano et al. 1987). In contrast, nitrate N may or may not differ between trees and interspace areas (DeBano et al. 1987, Klopatek 1987, Thran and Everett 1987).

Management Implications

Information on nutrient dynamics can be used for assessing the effect of different management strategies on the nutrient status and productivity of pinyon juniper woodlands. Important strategies include: grazing, fuelwood harvesting, and using prescribed fire either for type conversion or slash disposal following fuelwood harvesting. Tiedemann (1987) estimated N losses over a 100 year period would be 340 kg/ha by grazing and 856 kg/ha if chaining and burning were used for cover conversion. In contrast, fuelwood harvesting over the same 100 year rotation would remove only about 133 kg/ha of

Table 1.--Amounts of nitrogen, phosphorus, and potassium (kg/ha) in above-ground biomass and the 60-cm soil depth under trees and associated interspaces in pinyon-juniper woodlands, and percent in each ecosystem compartment.

Ecosystem compartment	N[1]		P[2]		K[2]	
Trees						
Foliage	108	(1)	20	(<1)	147	(4)
Twigs	184	(2)	11	(<1)	55	(1)
Wood	133	(2)	5	(<1)	21	(<1)
Litter	1,000	(12)	44	(1)	65	(2)
Soil (0-60 cm)	6,615	(82)	3,963	(98)	3,584	(93)
Total	8,040		4,043		3,872	
Interspaces						
Foliage	4	(<1)	0.2	(<1)	0.2	(<1)
Soil	4,527	(>99)	3,963	(>99)	3,584	(>99)

[1]Data from Tiedemann 1987.

[2]Data from DeBano et al. 1987.

[3]Percent of total nutrient pool made up by a particular ecosystem compartment.

N in the woody material. However, if prescribed fire was used for slash disposal following harvesting, an additional 277 kg/ha of N would be volatilized from twigs and leaves (if 95 percent of the N is volatilized) in addition to variable amounts of the 1000 kg/ha of N contained in the litter. If large amounts of litter were consumed by fire during slash disposal operations, then an additional 400 500 kg/ha of N could be lost. It is not known how grazing would affect P and K pools.

Fuelwood harvesting would remove only a small percentage of the P (5 kg/ha) and K (21 kg/ha) nutrient pools during a 100 year rotation. Substantial P would also be lost if the leaves and twigs were burned following fuelwood harvesting. Nonparticulate losses up to 50% of the total P (16 kg/ha) could occur if these fine materials were totally consumed during burning (Raison et al. 1985). A variable amount of the P contained in the litter could also be lost, depending on the intensity of the fire. Similar percentages of K may also be lost because it volatilizes at the same temperature as P (Raison et al. 1985).

The effect of different management activities on available nutrients is not as well understood as on total nutrient pools, although there is some information available on the effect of fire on nutrient availability. Studies in pinyon juniper and other ecosystems show fire acts as a rapid mineralizing agent, and releases ammonia N which is later converted to nitrate N when conditions are favorable for nitrification (Klopatek 1987). The release of highly available forms of N by fire portrays the impression that burning increases soil fertility on a site. However, total N is reduced, and increases in ammonia and nitrate N are short lived because these nutrients are rapidly immobilized biologically. Inorganic P also is released by burning, but it too is quickly immobilized chemically (DeBano and Klopatek, In press) and may no longer be readily available for plants. Harvesting also increases the concentration of nitrate N in soil surface layers (DeBano et al. 1987). Nitrate N

presumably increases because harvesting reduces inhibition of nitrification, eliminates trees which assimilate any nitrate N being formed, or changes the microclimate. Both soil moisture and temperature can be increased by harvesting (Everett and Sharrow 1985) which in turn may affect microbial relationships.

Summary and Conclusions

Pinyon and juniper trees enrich the surface soil beneath their canopies by cycling plant nutrients, both vertically from the subsoil and horizontally from adjacent interspaces. This produces a spatial distribution of nutrients roughly corresponding to existing tree canopy cover. Both N and P undergo extensive horizontal and vertical translocation. Important features of this vertical distribution pattern are: (1) a small percentage of the total nutrient pool resides in plant biomass and litter, and (2) N, P, and K differ in the proportion of a nutrient stored in living biomass and litter. The location of active nutrient pools beneath tree canopies makes them vulnerable to different management practices such as range improvement and fuelwood harvesting. Prescribed fire is used in both range improvement and slash disposal after fuelwood harvesting. Range improvement practices designed to permanently convert pinyon juniper stands to grasslands may have a major impact on the storage and cycling of both above and below ground nutrients, particularly if chaining and burning are used as part of the treatment. Fuelwood harvesting not only removes nutrients directly from the site, but also affects mineralization and the release of available nutrients remaining on the site. Prescribed fire acts as a rapid mineralizing agent, making part of the nutrient pool more readily available but at the same time volatilizing substantial amounts of nutrients from the litter and above ground biomass. These losses and changes in nutrient pools may affect the productivity of pinyon juniper woodlands.

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Glacier Lakes Ecosystem Experiments Site: An "Experimental" Wilderness

Douglas G. Fox, Anna W. Schoettle, and Frank A. Vertucci[1]

Abstract--This site, selected to be representative of high-mountain wilderness ecosystems, is being used to study the effects of air pollution and atmospheric deposition in alpine and subalpine, terrestrial and aquatic biotic communities. The research program includes (a) short-term experiments designed to quantify the response of system components hypothesized to be most sensitive to changes in ozone, S, and N air pollution and deposition; (b) development of operationally oriented models capable of predicting system, species, and biogeochemical responses; and (c) long-term biogeochemically-oriented monitoring to help establish the validity of (a) and (b) as management decision tools.

Wilderness is the most rapidly increasing land use within the National Forest System. Wilderness presents a unique set of challenges to managers. To date, management has largely been confined to controlling or minimizing visual effects. However, other stresses are operating in complex ways that cannot be seen. Of particular concern are effects caused by air pollution, and combinations of air pollution and climate change hypothesized to result from increasing human populations. A logical first step in scientifically based wilderness management involves monitoring these ecosystems over time. We have recently developed guidelines for this purpose (Fox, et. al. 1987).

It is well known that ecosystems change in response to natural internal dynamic processes as well as to both natural and anthropogenic external stresses. Our present knowledge of wilderness ecosystems does not allow us to distinguish the subtle differences between these change-causing factors. However, prudent management of wilderness requires that ecosystem effects resulting from changes in the chemical and physical climate be understood. From such understanding will develop management alternatives to help maintain these wildernesses as areas substantially "uninfluenced by the hand of man."

Just as we have learned how to manage commercial forest ecosystems through carefully controlled research studies, so also will we learn to manage wilderness by studying it. The research, however, is different from what has been done in the past. Questions involve sorting out the role of unseen stressing factors, components of the general environment, on ecosystem health. Issues relate to maintaining rare and endangered species where pertinent. Debate about the appropriate manner to gauge ecosystems, whether on a species or a functional level, must be resolved. Ensuring the vast biotic diversity among wildernesses is a new and unprecedented management objective.

These complex questions require research that considers the system from different perspectives. Research will require studying the response of tightly defined ecosystems to atmospheric inputs. Figure 1 illustrates the components of an ecosystem. The boxes represent transfers between components. The challenge in ecosystem research is constructing boundaries around these components that allow a mass balance of fluxing chemicals to be constructed with some accuracy. These "ecosystems" might be an entire watershed, a few tens of meters of a stream, or a very carefully isolated 1 m^2 patch of alpine soil. Common to all these differently defined ecosystems will be the ability to construct accurate nutrient budgets and to study, in a self-contained manner, processes of and interactions between the organisms and abiotic factors that consume, alter, and generate these nutrients. Species and community level dose/response experiments are being conducted to evaluate specific response hypotheses. Process-based models will be constructed to try to incorporate individual responses into system-level behaviors. Long-term monitoring data will be required to ensure the validity of hypotheses and models in the natural landscape.

Conducting such an extensive research program is incompatible with legally mandated wilderness. Rather, a location is required that (a) is not formally designated wilderness but has current and past uses like wilderness, (b) is remote but accessible year round, and (c) contains ecosystems that can be hypothesized to be sensitive to air pollution, acid deposition,

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and climate change. To find the best possible location for this research program, we spent 2 years evaluating potential locations. This involved a large number of scientists and a field season of data collection before the final site was selected.

Selection was based on a set of criteria that included logistical factors (ownership, permission to conduct research, accessibility, historic data) and ecological factors (excellent air quality, alpine/subalpine type, nonweatherable bedrock, lakes, water with ANC < 50 ueq/l, soils with base saturation less than 25%). Ecological criteria were based on the hypothesis that currently unimpacted systems exhibiting low buffering capacity are likely to be maximally sensitive to air pollution inputs. The buffering capacity was gauged by acid neutralizing capacity (ANC) of the surface waters, relative mineral weathering potential of bedrock, and exchange capacity of the soils. An alpine location was desired that collects large amounts of snow. The snowpack effectively accumulates and stores pollution on the site until spring melt. Spring brings a pulse of chemicals delivered rapidly to the ecosystem. This can result in a temporary change in lake chemistry which, depending on lake pH, may cause changes in the biotic complex. Such a location is clearly the most sensitive from an aquatic perspective. In clean air, ozone concentrations tend to increase with elevation. Climate influences are dominant factors in the alpine, tree line providing a dramatic example. It is therefore reasonable to hypothesize that alpine locations will be most sensitive from a terrestrial perspective as well.

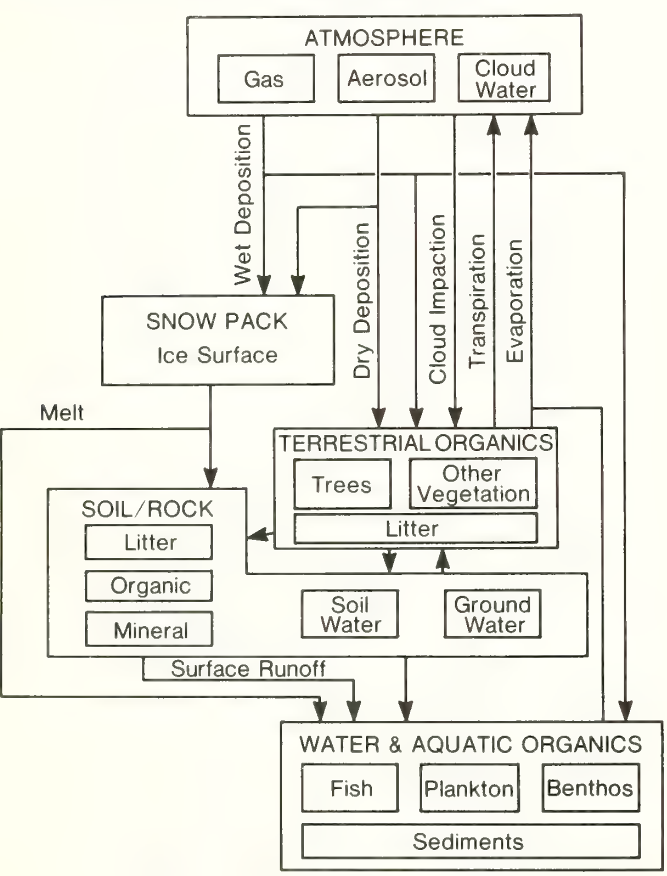

Figure 1.--Box and line diagram of GLEES.

All these criteria are met at the Glacier Lakes Ecosystem Experiments Site (GLEES).The site and the research program currently underway there are described in the remaining sections of this paper.

GLACIER LAKES ECOSYSTEM EXPERIMENTS SITE

Location and Topography

GLEES is located on the Medicine Bow National Forest approximately 65 km W of Laramie, Wyoming. The site is a high (3,400 m) glacial cirque basin, containing three small lake watersheds (104, 52, and 43 ha) fed by first-order perennial streams generated from permanent snow fields (fig. 2). Vegetative cover is primarily subalpine, with a sparse Engelmann spruce-subalpine fir forest (including krummholz stands), forb-dominated snowpatch communities, and sedge meadows. Soils are minimally developed. Geologically, the basin is uniform quartzite (75-80%) crossed by intrusions of amphibolite, a mineralogically complex and active mafic rock. Water chemistry is dominated by snow chemistry except for streams that run through sufficient mafic materials to reflect weathering processes. Lake water is extremely low in ionic strength; alkalinities are on the order of 40 ueq/l.

Meteorology and Air Quality

Data have been collected in the vicinity of the Glacier Lakes since the late 1960's, primarily for measuring the contribution of the Snowy Range to Wyoming water resources (Wesche 1982). Mean temperatures measured near the watershed range from lows of -10° F to highs of 30° F in winter and lows of 20° F to highs of 70° F in summer. Wind speed, on the exposed locations of the watershed, can average above 15 mph for months at a time. Precipitation is highly variable across the watershed but averages 35 inches at Lost Lake, 42 inches between East and West Glacier Lakes, and 49 inches near the East Glacier Lake outlet.

Although no air quality measurements have yet been recorded, the area is assumed to be clean based on the chemistry of precipitation. A wet/dry precipitation collector operated by the Wyoming Water Research Center for the National Acid Deposition Program on the southwest side of West Glacier Lake since April, 1986, indicates sulfate and nitrate concentrations generally below western averages.

Air quality measurements will be initiated on the watershed in 1987.

Geology and Soils

The geology of GLEES has recently been described by Rochette (1987) and the soils by Hopper and Walthall (1987). Local alpine glaciation caused three cirques or nivation basins

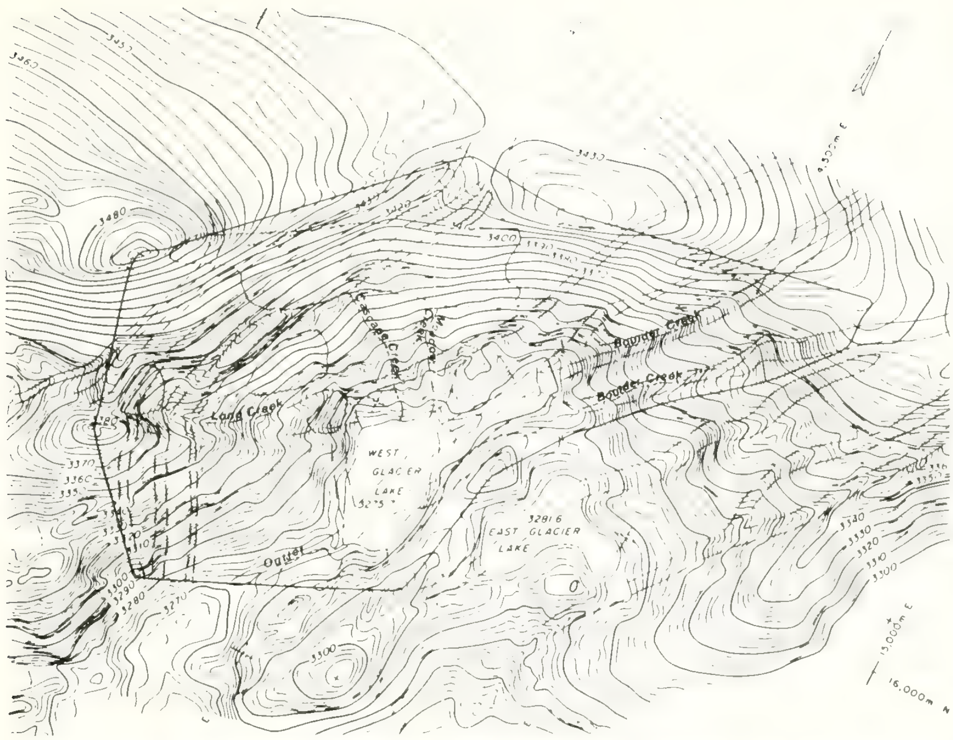

Figure 2.--The GLEES contour and geologic map. Dashed lines illustrate mafic dykes into the surrounding quartzite. The geological mapping is only in the boxed areas.

to form on the south side of the primary ridge line. Bedrock is quite uniform, consisting of Medicine Peak quartzite intruded with 15-20% mafic dykes of amphibolite. The significance of the mafic rock is that it is considerably richer in minerals. The chemistry of surface waters in the streams feeding West Glacier Lakes appears to be dominated by weathering of the mafic rocks. Nevertheless, this weathering rate is not likely to increase with acid deposition, and because of minimal soil-water contact, the watersheds are considered quite sensitive to increases in acid deposition (e.g., the watershed buffering capacity is small) (Rochette 1987).

Vegetation

The watersheds are predominantly subalpine with considerable abundance of alpine taxa (Simmons 1987). The forested areas (35% of the area) are Engelmann spruce- subalpine fir, which also form krummholz stands at more exposed locations (fig. 3). An occasional limber pine can be identified. A total of 135 plant taxa have been identified on the watersheds. Many are alpine species, particularly in the meadow and cushion-plant assemblies. Herbaceous vegetation types (meadows, cushion-plant-dominated ridge tops, and partially vegetated scree) make up 30%, while willow-shrub types (willow and wet meadow willow) comprise the remaining 5%, which is significantly vegetated.

Lakes and Streams

Lost Lake is the largest (6 ha) and highest (3332 m) of the three lakes. East Glacier Lake is 2.8 ha with a watershed of approximately 43 ha. West Glacier Lake is 2.6 ha with a watershed of approximately 52 ha. Four streams, as shown in figure 2, feed West Glacier Lake. Inflow to East Glacier Lake is largely accomplished by nonchannelized flow and therefore, appears to be relatively more subject to interactions with watershed soils and vegetation.

Lakes and the West Glacier outlet stream support brook trout populations. In addition, East Glacier supports a cutthroat trout population. Macroinvertibrate sampling suggests a relatively depopulate community of cold water species in the stream. Lake and stream acid neutralizing capacities are low ranging between 30 and 50 ueq/l.

THE RESEARCH PROGRAM

The site will be used for long-term ecosystem study. The study will be watershed oriented, namely individual watersheds and subcatchments within these watersheds will be identified, gauged, and studied. Figure 1 can be used to represent a simple conceptual model of the GLEES. Our research plans include measurement of the reservoirs and as many of the transfers as are practical. Within this framework,

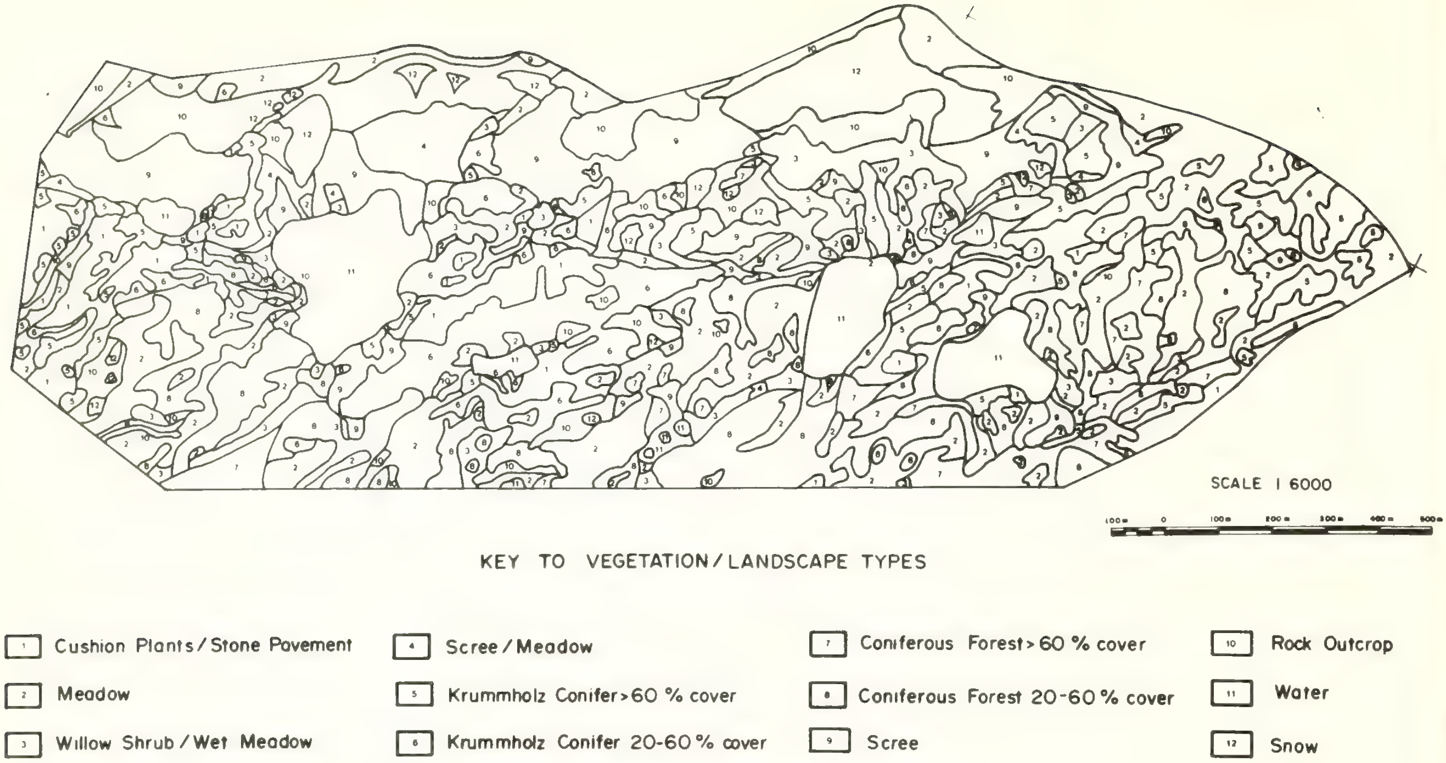

Figure 3.--Vegetation and landscape types on the GLEES.

detailed budgets associated with the reservoirs themselves will be constructed. Where possible, paired systems will be identified or constructed so that manipulation experiments can be conducted with controls.

Atmospheric Compartment

The careful measurement of atmospheric input to the GLEES will be a hallmark of this research. In addition to measurements, the Topographic Air Pollution Analysis System (TAPAS), a comprehensive set of meteorologically based state-of-science computer simulation models will be used to help characterize the atmospheric compartment. Specific studies include:

Meteorology.--The objective of meteorological studies is to characterize the overall meteorology and climate of the GLEES. The relatively uniform terrain of the GLEES allows a minimum of measurements to accomplish this (fig. 4). Instrumentation has been installed at two locations on the GLEES. At each a tower has been erected well above the forest vegetation. Both are instrumented with wind speed, direction, temperature, and humidity. Planned expansion includes multiple levels of turbulence and radiation instrumentation.

Air Quality.--The objective of air quality measurement is to help characterize chemical inputs to the GLEES. It is a measure of the amount of chemicals in the atmospheric compartment and helps in the measurement of dry deposition, one of the major unknown transfers from the atmospheric compartment.

Wet Deposition.--The objective of wet deposition measurement is to further characterize chemical inputs to the GLEES. It also is a major transfer from the atmospheric compartment. A wet deposition collector has been operating at the site since Spring, 1986. Additional bulk precipitation samplers will be installed at various locations on the GLEES in order to establish input chemical variances.

Dry Deposition.--The objective of dry deposition research is to try to directly measure this most illusive component of atmospheric transfer. To date no dry deposition measurement has been made in a complex-terrain forested setting.

Snow Pack Compartment

Snow pack is considered a separate component of the ecosystem because of its importance to the collection and delivery of air pollution and deposition to alpine systems. One cubic meter of snow contains approximately 104 square meters of surface area, about 2 football fields. This vast surface area is available to collect and hold pollution. Considerable research on snow chemistry and physics processes is underway within the Atmospheric Deposition Effects research unit. An ambitious field research program centers around an attempt to characterize the rapidly changing chemistry of melting snow.

Terrestrial Organic Compartment

Our interests in the terrestrial compartment are both with the transfer of atmospheric chemicals and nutrients into this compartment and with dose/response studies of selected

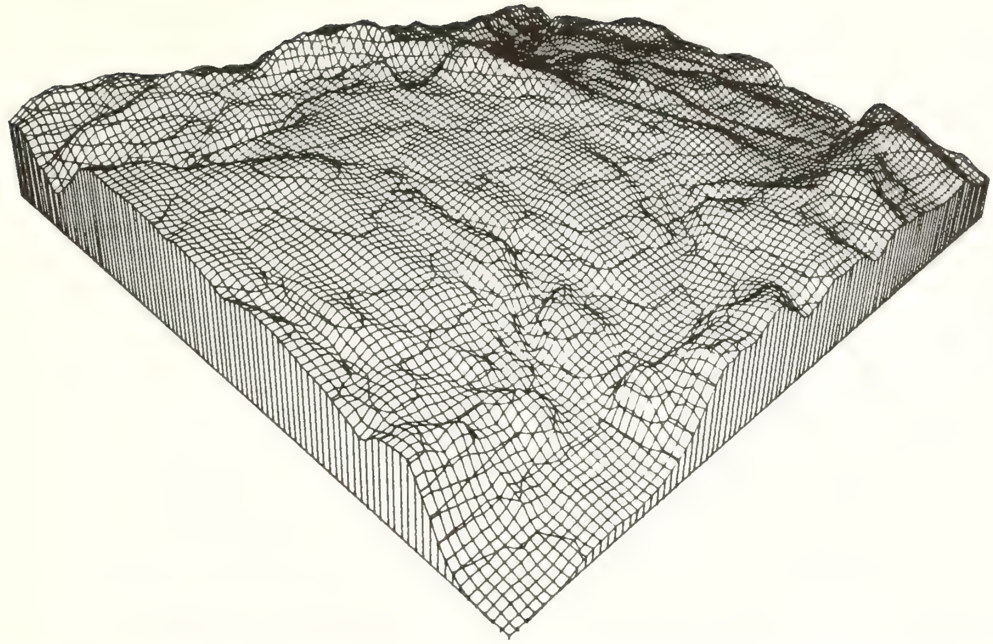

Figure 4.--A three-dimensional perspective of the GLEES vicinity. The maps in later figures cover the boxed area. Centennial is located in the lower corner of the map. The map was produced by the Topographic Air Pollution Analysis System (TAPAS) (Fox, et.al. 1986).

species within this compartment. The objective of this research is to establish the relative sensitivity of the alpine floristic component of the GLEES to air pollution and deposition. The first step in this research is to attempt to use a combination of physiological and morphological information to screen plants for their theoretical sensitivity. This is a field activity that will be conducted at the GLEES. The second step requires manipulation of the "theoretically" sensitive plants by subjecting them to elevated pollution and deposition.

Soil, Rock and Ground Water Compartment

A soil map of the GLEES has already been prepared. The ability of the soil to consume H^+ will be studied using the soil map along with laboratory studies of the soil chemistry such as SO_4 and NO_3 sorption, cation leaching, etc.

Water and Aquatic Organics Compartment

Stream Study

The chemistry and biology of a pair of streams, Cascade and Meadow, will be characterized. One stream will be manipulated by the input of sulfuric and nitric acid. Effects on the stream biota will be measured. This study will utilize the recently constructed gauging stations for each stream, input reservoirs at the stream head, drift nets and emergence traps (houses over stream).

Lake Studies

We also will attempt to characterize the role played by the lake in nutrient dynamics of the system. In addition to the morphometric survey already completed, sediment mapping and coring will be conducted including introduction of a paleolimnological tracer for the future. Seepage meters will be installed on transects in the lake bottom. The Parshall flumes in GLEES will be used to aid careful measurement of the hydrological balance of the watershed.

Fish surveys will be conducted as needed to determine the biomass and condition of this resource. Plankton productivity will be studied with small containers suspended in the lake closed to the system but containing carbon 14. Benthos will be surveyed by scuba divers.

SUMMARY

A broadly based ecosystem research program has been initiated on the Glacier Lakes, Medicine Bow NF, Wyoming. The ecosystem on the Glacier Lakes is alpine/subalpine and in a natural state. Minimal management activity is conducted on this area which is prototypical of much of the Wilderness system in the western US. The Glacier Lakes site can be considered an experimental wilderness. It is expected to exhibit extreme sensitivity to changes in atmospheric inputs of chemical nutrients and energy. The research program planned for the Glacier Lakes will provide new information for managers in the 21st Century. This information is likely to be

centered around increased world population and manifested in the form of increased recreational use of areas like the Glacier Lakes, and changed climate as a result of increased air pollution.

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Bird-habitat Relationships in Subalpine Riparian Shrublands of the Central Rocky Mountains

Deborah M. Finch[1]

Abstract--Breeding birds were counted in 1982, 1983, and 1984 using the spot-map method on seven 8.1-ha plots in the Medicine Bow National Forest, Wyoming. At elevations of 2,280 to 3,000 m, riparian habitats were structurally simple, dominated by one or more bush willow species. Subalpine riparian avifaunas were depauperate with only four abundant species-- song sparrow, white-crowned sparrow, Lincoln's sparrow, and Wilson's warbler. Habitat requirements overlapped among these species but differed significantly from randomly-sampled habitat in the same areas. Results indicated that species preferred densely-foliated ground and shrub layers, and higher effective vegetation height. Factors complicating efforts to characterize bird-habitat relationships are discussed.

Many factors complicate efforts to characterize relationships between wildlife abundance and habitat structure (Best and Stauffer 1986). These factors include population and species variability in time or space, measurement or sampling error, sampling scale, and inappropriate statistical methods. Models of wildlife-habitat relationships that are derived from limited or misrepresentative data sets produce indices that are not predictive or reliable.

Population size can vary from year to year, from season to season, and from site to site (Gaud et al. 1986). Factors that cause temporal and spatial variability in populations of terrestrial bird species include changes in weather and climate (Wiens 1981a, Szaro and Balda 1986, Hejl and Beedy 1986, Diehl 1986), qualitative and quantitative changes in food and habitat resources along environmental gradients (Karr 1980, Noon 1981a, Rice et al. 1983), and interspecific interactions (Terborgh and Weske 1975, Terborgh 1985). Error in estimating population size may result from observer differences, measurement error, inappropriate census methods, or insufficient sample size (Ralph and Scott 1980, Verner 1985, Stauffer and Best 1986). Scale of observation may affect evaluation of animal responses to habitat trends (Wiens 1981b, Wiens 1986, Maurer 1985, Morris 1987, but see Bock 1987). Sampling at a single site, multiple sites in a local area, or many geographical areas may produce different interpretations of species requirements, depending on the level of resolution.

A greater understanding of the factors that complicate interpretations of wildlife-habitat relationships is needed to reduce estimation error. Multiple year studies over a large number of sites, vegetation types, and localities are the best designs for explaining variation in bird abundance, but time and expenses may be prohibitive. In this paper, I examine associations between bird abundance, habitat structure measured at random sites, and habitat measured at bird locations in subalpine riparian shrublands. I considered the confounding effects of 1) year-to-year variation in numbers of four breeding bird species, 2) variation in bird abundance across sampling plots, 3) variation in species responses to habitat structure, and 4) sampling at plot and gradient levels of resolution.

Methods

Study Areas

Seven 8.1-ha study grids were established in the summer of 1981 in shrub willow habitats along drainages in the Medicine Bow National Forest of southeastern Wyoming (table 1). Each grid was posted at 33.5-m intervals with wooden stakes painted fluorescent orange and marked with grid coordinates. Grid dimensions were adapted to the variable widths of the streams

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Table 1.--Three-year (1982, 1983, 1984) means + standard deviations of numbers of spot-map pairs of four subalpine bird species counted on seven 8.1 ha riparian plots in the Medicine Bow National Forest, southeastern Wyoming. Plot drainages are arranged in ascending elevational order. F-ratios and probability levels of two-way ANOVA testing YEAR and PLOT effects on species counts are given.

Reference number	Drainage	Elevation (m)	Wilson's Warbler	Song Sparrow	Lincoln's Sparrow	White-crowned Sparrow
1	Wagonhound Creek	2,286	0	8.7 ± 1.8	0	0
2	S. Lodgepole Creek	2,470	0	10.3 ± 2.9	12.0 ± 4.6	0
3	N. Lodgepole Creek	2,530	0	9.0 ± 3.1	13.3 ± 2.2	0.3 ± 0.3
4	Douglas Creek	2,591	19.0 ± 2.7	3.0 ± 0.6	27.3 ± 3.5	8.0 ± 1.5
5	Lake Creek	2,789	5.5 ± 0.5	0	17.0 ± 0.0	4.0 ± 0.6
6	Lower Middle Fork Little Laramie River	2,930	6.0 ± 0.6	0	13.3 ± 1.7	4.0 ± 0.6
7	Upper Middle Fork Little Laramie River	2,987	6.0 ± 0.6	0	9.3 ± 0.3	10.0 ± 1.2
	F-Ratio (P)[a]					
	YEAR effect		3.18 (N.S.)	0.96 (N.S.)	0.15 (N.S.)	3.19 (N.S.)
	PLOT effect		4.99 (*)	6.50 (*)	22.40 (*)	31.65 (*)

[a]*$P < 0.01$, N.S. = not significant. Numerator and denominator degrees of freedom are 2 and 12 for YEAR effect and 6 and 12 for PLOT effect.

in the following combinations: 3 x 24 squares (plots 4, 5, 9 and 10); 2 x 36 (plot 6); 4 x 18 (plot 7); and 6 x 12 (plot 8).

Study grids were distributed over an elevational continuum ranging from 2,286 m to 2,987 m. Vegetation on plots 1 to 3 was dominated by one or several shrub willow species including *Salix bebbiana*, *S. exigua*, *S. geyeriana*, *S. planifolia*, *S. boothii*, and *S. lasiandra*. Additional shrubs that were locally common on these mixed willow plots were thinleaf alder *(Alnus tenuifolia)*, western snowberry *(Symphoricarpus occidentalis)*, common chokecherry *(Prunus virginiana)*, serviceberry *(Amelanchier alnifolia)*, and red-osier dogwood *(Cornus stolonifera)* (see Finch 1987 for complete shrub list). Small isolated patches of quaking aspen *(Populus tremuloides)* were also present. Surface understories were dominated by *Calamagrostis canadensis* and *Carex* spp. These drainages were typically bordered by sagebrush *(Artemisia tridentata)*, grassland, and lodgepole pine *(Pinus contorta)* forest.

On higher elevation (> 2,600 m) plots, *S. planifolia* was found in monocultures or mixed with *S. wolfii*. The subalpine parks formed by these willow thickets were associated with wet, boggy meadows of *Deschampsia cespitosa* and *Carex* spp., surrounded by mixed stands of Engelmann spruce *(Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)*. A more detailed account of plant species distributions in the Medicine Bow Mountains can be found in Nelson (1974).

Sampling Bird Populations

Birds were counted on the seven study grids using the spot-map method (Robbins 1970) from mid-May through early July of 1982, 1983, and 1984. A minimum of eight visits was made to each study plot each year, and each visit lasted from 2 to 4 hours beginning at daylight. Edge clusters were counted as belonging to the plot if more than half of the observations were recorded within or on the plot boundaries. Netting and banding information were used to substantiate the presence of pairs in cases where mapping information was inconclusive (Verner 1985). See Finch (1986, 1987) for more details on procedures for counting birds, and overall count results.

Sampling Habitat Structure

Four bird species were selected for analyses of bird-habitat relationships based on their high relative abundances in subalpine riparian communities: Wilson's warbler *(Wilsonia pusilla)*, song sparrow *(Melospiza melodia)*, Lincoln's sparrow *(Melospiza lincolnii)*, and white-crowned sparrow *(Zonotrichia leucophrys)*. Habitat structure was sampled in July and August of 1982, 1983, and 1984 within the mapped territories of these four species, either near nest sites or at male singing locations. Bird-centered vegetation sampling was developed by James (1971) and recommended by Larson and Bock (1986) as a powerful tool for evaluating habitat relationships because it is precise and efficient, and because data can be pooled at various spatial scales (e.g., study plots, set of local plots, or geographical region). A total of 134 territories were sampled across the set of study plots. Sample data were pooled for each species to give estimates of associated habitat characteristics at each study plot as well as over all plots. These data were used to assess the effects of habitat variation among plots separately from species responses to habitat, but only values for habitat features averaged over all plots are reported here.

For comparison, 40 random locations in each study grid were sampled in a mode identical to the bird-centered samples. Random sampling sites were located by selecting grid coordinates from a table of random numbers. Random sample data were pooled to give estimates of habitat features for each plot and all plots combined.

At each sampling location, a set of 34 structural habitat variables was measured following a point-centered quarter sampling procedure recommended by Noon (1981b) for shrub habitats. Habitat features were sampled by dividing each location into four quadrants oriented in the cardinal compass directions. Twenty-one of the original variables were deleted from the final analyses because they were invariant, highly correlated with other variables, or irrelevant with regard to subalpine shrub habitats. Descriptions and sampling techniques for the remaining 13 variables are presented in table 2.

Data Analyses

Two-way ANOVA was performed to detect variation in number of pairs of each species among years and among study plots. Data for three years and seven plots were used to determine main effects of the two factors, YEAR and PLOT. Because no interaction was observed between YEAR and PLOT, the three-year bird count data were averaged for each species in other analyses.

Nested design analysis of variance was used to test for differences in habitat structure between random and bird-centered locations (BIRD effect) among seven plots (PLOT effect). Random and bird-centered sites were compared (nested) within each plot before PLOT effect was computed so that plot-to-plot variation in habitat structure would not interfere with assessment of bird-habitat associations. Each of the thirteen habitat variables was analyzed using a univariate approach. Only the BIRD effect is reported here in order to focus on the factor of main interest. Nested ANOVA's were also used to assess variation in habitat selection among the four bird species (SPECIES effect), and between all birds pooled versus random sites (ALLBIRD effect) across seven plots.

The relationship between trends in each habitat variable and numbers of pairs of each species across the seven plots was examined using Pearson product-moment correlation coefficients. Averaged three-year count data and averaged random habitat data for each study plot were used to produce positive or negative bird-habitat associations. Significant associations were determined using two-tailed t tests.

Analyses were performed using SPSS and SPSS Update 7-9 statistical packages (Nie et al. 1975, Hull and Nie 1981) and SPSS/PC + programs (Norusis 1986). Analyses of raw and log-transformed variates (Kleinbaum and Kupper 1978) produced biologically and statistically similar results. Results of raw data analyses are reported here for ease of interpretation.

Results

Trends in Bird Numbers

Mean yearly numbers of avian pairs varied substantially among the four bird species over the seven study areas based on the results of a one-way ANOVA (F-test= 3.57, $P < 0.05$).

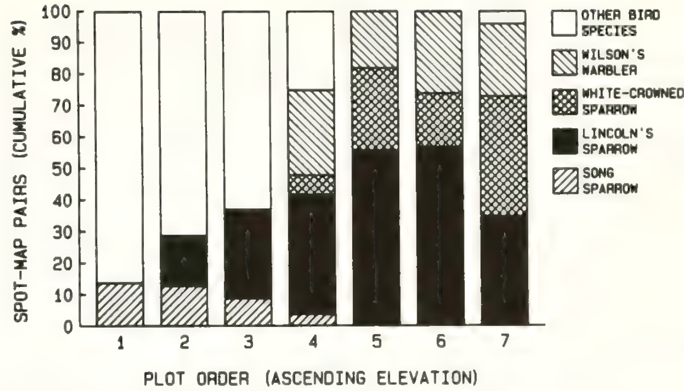

Figure 1.--Population trends of four subalpine bird species counted on seven study areas in 1982, 1983, and 1984. Counts are arranged by plot elevation.

In the three study years, song sparrow numbers declined with increasing plot elevation, disappearing altogether at higher elevations (fig. 1). The distribution of Lincoln's sparrow moderately overlapped with song sparrow, but showed an opposite trend of increasing numbers with ascending elevation (fig. 1). Wilson's warbler and white-crowned sparrow co-occurred on the four highest plots and were absent from lower study areas. Two-way ANOVA indicated that year-to-year variation in population numbers of each species was low compared to variation due to study area differences, and therefore averaged three-year counts were used in analyses of bird-habitat relationships (table 1).

On two of the lowest-elevation plots, Lincoln's sparrow and song sparrow shared the habitat with a complex bird species assemblage (Finch 1987), and as a consequence, both species comprised only 14-37% of the avifauna (fig. 2). In contrast, Lincoln's sparrow alone dominated the four higher subalpine plots, composing 35-57% of the avian community, followed by Wilson's warbler with 18-27% and white-crowned sparrow with 6-38% (fig. 2). These three subalpine species constituted 75-100% of the riparian avifauna censused at elevations of 2,600 m and above.

Avian Habitat Selection

Thirteen structural features were useful in describing within-plot habitat selection patterns of subalpine riparian bird species. In the ground layer of vegetation, vertical foliage density was significantly higher at sites occupied by Wilson's warbler and white-crowned sparrow than at randomly-measured sites, and in the low shrub layer, foliage was denser at sites selected by all four species than at random sites (table 2). Selection for dense foliation in the low shrub stratum is reflected in the significant variation in this habitat feature between random sites and all bird species pooled (ALLBIRD effect, table 2). Vertical foliage density in the tall shrub layer did not differ significantly between random and bird-centered sites. All four species also selected sites with greater-than-random effective vegetation height, which is an alternate

measure of vegetation volume. This habitat feature also varied among bird species (SPECIES effect) as well as between random sites and all birds pooled (table 2).

Song sparrow chose territorial sites within plots that had greater-than-random canopy cover, but the other three bird species showed no trend (table 2). Wilson's warbler and white-crowned sparrow strongly ($\underline{P} < 0.0001$) selected sites that were thickly covered by shrubs < 1 m (mean cover > 44%) and other woody material (mean cover > 56%). In contrast, at random sites, small shrub coverage was only 28%, and coverage by woody matter was only 43%. To a lesser extent ($\underline{P} < 0.05$), song sparrow also chose sites with greater shrub and woody cover, but Lincoln's sparrow was distributed in a close-to-random manner with respect to all ground cover features. Sites with grass/forb coverage as high as the random value of 52.5% were not used by Wilson's warblers and song sparrows, and Wilson's warbler also avoided sites with bare ground (table 2). Percent cover by small shrubs, grass/forbs, and bare ground varied substantially among the four species, but only small shrub cover varied between random sites and the entire group of species.

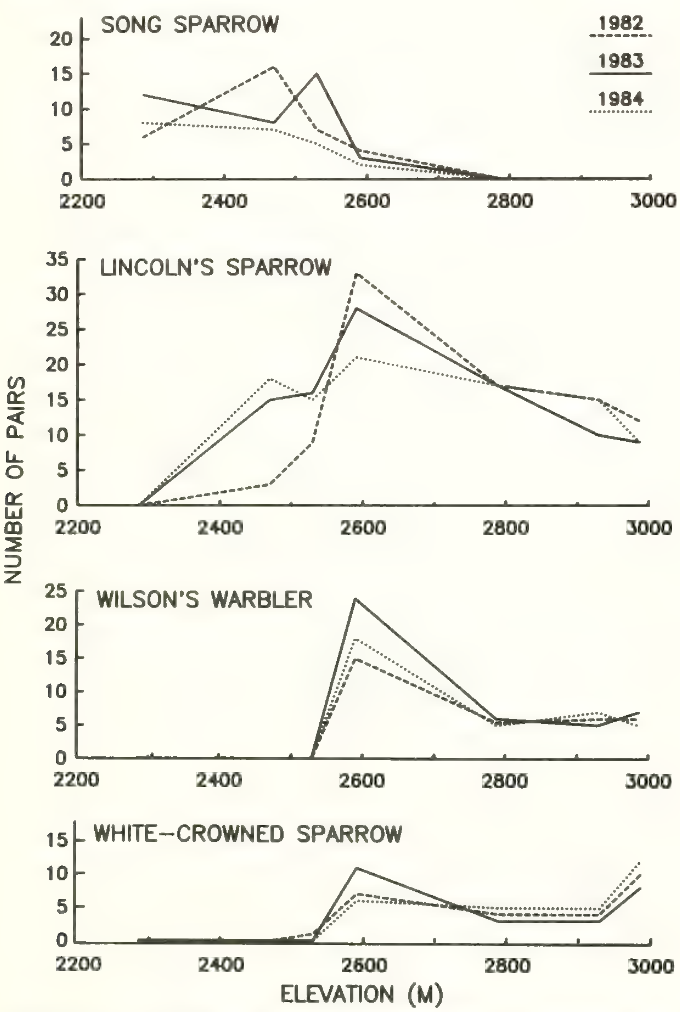

Figure 2.--Dominance patterns of four subalpine bird species based on number of territorial pairs counted on seven study plots listed by ascending elevation.

Wilson's warbler chose subalpine sites with lower shrub crown diameters and shrub height than random sites whereas song sparrow chose sites with larger-than-random shrubs. These two shrub size characteristics were also important in distinguishing among species locations within study areas (SPECIES effect, table 2). In contrast, shrub dispersion and percentage fruiting shrubs were shrub features that differed from random values at sites occupied by Lincoln's sparrow and white-crowned sparrow, as well as at locations selected by all birds (table 2).

Bird Densities and Habitat Trends

I used correlational analyses to identify relationships between mean 3-year counts of each species and mean habitat features over all study areas. This evaluation of abundance patterns substantiated patterns of habitat selection evident in the analyses of random versus bird-centered data, but detected other habitat selection trends as well.

Wilson's warbler plot densities were significantly and positively correlated to foliage density in the low shrub layer, effective vegetation height, and woody cover, and negatively associated with grass/forb cover (table 2). These relationships are similar to those found in the bird-centered habitat data. Numbers of song sparrows were also associated with several features relevant in the bird-centered habitat analysis; additionally, song sparrows increased in numbers on plots with greater foliage density in the tall shrub layer and higher mean shrub height. Higher numbers of Lincoln's sparrow were associated with plots that had high vegetation surface foliage density, and low percentages of bare ground cover and fruiting shrubs. Reduced canopy cover was the only habitat variable significantly associated with increased white-crowned sparrow densities.

Discussion

Temporal Effects

Abundances of four migratory nesting bird species remained relatively stable over the three-year study period, and therefore year-to-year variability did not confound attempts to interpret bird-habitat relationships. Although longer-term studies are needed to verify temporal stability in these subalpine riparian bird populations, other studies have indicated that only numbers of permanent residents varied significantly among years, probably because of severe over-wintering mortality (Beedy 1982, Raphael and White 1984, Hejl and Beedy 1986). Lack of year-to-year differences in migrant abundances in this study suggests that winter conditions were not harsh enough to depress numbers on the wintering grounds, and therefore no changes were observed on the breeding grounds.

Effects of Plot Variation

Population size of all four bird species varied substantially across sampling plots. The seven study plots represented a vegetational and altitudinal gradient from mixed-shrub willow habitats to subalpine willow parks composed primarily of *Salix planifolia*. Changes in bird abundance were related to two major trends in habitat structure. Structural complexity was reduced at higher elevations as shrub species diversity, shrub size, canopy cover, and foliage density in the tall shrub layer declined (Finch 1987). Concomitantly, woody cover and foliage density in the surface and low shrub layers increased. Probably in response to these habitat changes, Wilson's warbler, white-crowned sparrow and Lincoln's sparrow, species that occupy sites with low, densely-foliated shrubs, reached peak abundance on the higher plots. Lincoln's sparrow was distributed over a greater range of plots usually at higher densities than other species, demonstrating greater flexibility in habitat use. Lincoln's sparrow was absent, however, from the lowest plot, possibly in response to reduction of preferred habitat due to elevational changes. Song sparrow, a species that selects tall shrub sites, had greatest densities on lower plots.

Characterizations of song sparrow-habitat relationships based on these results are only applicable for subalpine riparian habitats. Song sparrows are present at reduced densities in lowland cottonwood-willow habitat in the Rocky Mountains (Finch 1987). By excluding the cottonwood vegetational type from this analysis, data for describing the association between song sparrow abundance and habitat changes are incomplete. Gradient sampling in the other three bird species was probably adequate based on the lack of pronounced truncation in abundance trends (fig. 1).

Variability in Species Responses

In this study, each bird species responded differently to habitat variation. Strategies for managing single bird species in subalpine riparian habitats will therefore differ from those developed for groups of species. Effective management designs should rely on principles derived from bird-centered habitat features that significantly differ from random sites, either for each bird species or for the bird assemblage as a whole.

To produce an increase in Wilson's warbler and white-crowned sparrow numbers, habitats can be enriched if foliage density, cover, and abundance of subalpine willows are increased and coverage by open meadow and bare ground is reduced. Lincoln's sparrow is unrelated to most of the measured habitat features, achieving dominance on most shrub willow sites. Management schemes that emphasize subalpine avian specialists like Wilson's warbler (see Finch 1987) should enhance areas for Lincoln's sparrow as well. Lower-elevation riparian areas with larger shrubs are selected more heavily by song sparrows. Habitats within this range can be enhanced by managing for greater canopy cover, shrub size, and shrub cover than that which is randomly available. To improve habitat for all four species, efforts should concentrate on increasing shrub density and cover while emphasizing diversity in shrub height, crown diameter and dispersion, and surface cover of small shrubs and ground vegetation. Some of the damaging effects of livestock grazing on bird habitat can be mitigated if these recommendations are followed.

Sampling Scale

At the resolution level of the entire spectrum of plots, species densities were related to one or more vegetational features that changed over the elevational cline. Bird-habitat relationships models developed from these kind of data merely require population-monitoring along gradients of randomly-measured habitat. Within a local area, however, birds occupied habitat patches that differed from randomly-available habitat. In this study, each species selected sites within plots that differed from random sites for a variety of habitat features. Thus, sampling random habitat and bird abundance across many plots produced correlational information at a large scale, but the results do not apply for a specific locality.

Choice of sampling scale (e.g., single vs. multiple plots) and sampling intensity (e.g., random sampling only vs. bird-centered sampling) depends on study objectives and time and budget constraints. Site-specific studies using bird-centered data yield more detailed information on bird-habitat associations, but bird-centered data take much greater time and labor to collect, and results may only apply for a local area. I recommend sampling habitat at both bird-centered and random sites over a variety of vegetational types if managing a single species or guild in a specific locality is the goal. Such a sampling regime will provide more complete coverage of an animal's distribution and habitat requirements. Random sampling alone may be necessary if time and cost demands are prohibitive, or if the goal is to characterize habitat associations of large assemblages of birds in multiple habitats.

Acknowledgements

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The Coon Creek Wildlife Project: Effects of Water Yield Augmentation on Wildlife

Martin G. Raphael[1]

Abstract--The Coon Creek Water Yield Augmentation Pilot Project is a demonstration of timber harvest designed to increase water yield from a treated drainage compared to an untreated control. Of interest here are the effects of this pattern of timber harvest on bird and small mammal community structure, and on the distribution, habitat selection, and reproductive success of selected species. This paper describes preliminary results during the pretreatment phase of a longer-term study.

Subalpine forests of spruce, fir, and lodgepole pine are the largest and most valuable timber resources in Colorado and Wyoming (Alexander 1974), accounting for over 38% of the 13 million hectares (ha) of forest land and over 90% of sawtimber volume (USDA Forest Service 1980). These forests also provide habitat for 45 mammal, 93 bird, 2 reptile, and 5 amphibian species (Hoover and Wills 1984: Appendix A).

Subalpine forests in the central Rocky Mountains are harvested not only to provide timber, but also to increase water yield and other benefits (Alexander et al. 1983). The Rocky Mountain Region of the Forest Service proposed the Coon Creek Water Yield Augmentation Pilot Project (Bevenger and Troendle 1985) to (1) apply current best management practices to optimize water yield on an operational scale; (2) evaluate effects of current methods on yield, quality, and timing of water flow and timber production; and (3) test reliability of the state-of-the-art Subalpine Hydrological Model as a prediction tool on an operational scale.

The Coon Creek and Upper East Fork drainages of the Encampment River were selected for this project because they are large enough to expect a measurable effect; are of comparable size, aspect, elevation, and timber cover; and are commercially harvestable. Pre-treatment hydrologic data collection was initiated by National Forest personnel in 1983. Timber har- vest, consisting of 350 clearcuts averaging 3.8 acres (range 0.5-14.8 ac), is expected to begin in 1989 on the 3,987-acre Coon Creek watershed. The 2,252-acre East Fork watershed will remain uncut as a control.

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Our wildlife studies are designed to assess the impact of this water- yield harvest pattern on species composition and abundance of terrestrial wildlife. This study was begun in May, 1985 and will continue for at least three years following timber harvest. This report summarizes results of the first two years, emphasizing a comparison of vegetation between the two watersheds and wildlife populations among habitat types.

Study Area

The Coon Creek and Upper East Fork drainages are located in the Sierra Madre range in southern Wyoming. Elevations vary from 2,600 m to 3,300 m. Soils in both drainages vary between 50-150 cm deep and are well-drained. Mean yearly precipitation is about 100 cm, 70% of which occurs as snow. Forest cover is dominated by lodgepole pine (~60%) and Engelmann spruce/subalpine fir (40%). Pole stands (<23 cm d.b.h.) occur on 24% of the combined area of the two watersheds; sawtimber stands cover 72% and meadows or rock outcrops cover the remaining 4%.

Methods

Vegetation Sampling

Ninety sampling stations were established in each watershed (fig. 1) along N-S lines at 400-m intervals with 200 m between stations along each line. A single observer visited each sampling station in August, 1985 and measured basal area of each tree species using a metric Reloskop. Canopy cover was estimated from the average of four readings using a spherical densiometer. All snags >20 cm d.b.h. and 1.8 m tall

were counted within a 0.04-ha circular plot centered at the station; percent cover of shrubs, forbs, grasses, rocks, litter, and bare ground were visually estimated over the same 0.04-ha plot. Hard (class 1,2) and soft (class 3,4,5 [see Maser et al. 1979]) logs were also counted on each plot. Height and d.b.h. of one representative tree was measured at each station using a clinometer and metric d.b.h. tape.

All stands on each watershed were cruised by personnel of the Medicine Bow National Forest and assigned an old-growth rating based on canopy structure, d.b.h., tree height, snag size and density and log size and density. Possible scorecard values range from 0 (no old-growth characteristics) to 60 (maximum). Stand maps were used to associate a sampling station with the old-growth scorecard value for the stand in which the station was located.

Bird Community Structure

Three observers visited each sample station twice each year (for a total of six visits/station/year) from 13 June to 25 July 1985 and from 18 June to 23 July, 1986. At each visit, an observer recorded all birds and red squirrels heard or seen during a timed 10-min period and recorded the distance from the station center to the bird or squirrel. All counts were begun within 30 minutes after sunrise. Each observer visited 15 stations/day so that most counts were completed before noon.

Small Mammal Community Structure

To sample shrews, six pitfall traps were installed in a 2 x 3 grid (15-m spacing) centered on each station. Each pitfall trap was a 3-gal plastic bucket buried flush with the ground surface and covered by logs or bark. To capture other small mammals, observers placed two 50-cm Sherman livetraps within 2 m of each pitfall station.

Mammals were trapped over a 6-week period from 20 August through 26 September, 1985 and 5 August to 11 September, 1986. Observers checked traps daily during each of three, 10-day sampling sessions per year. All captured specimens were identified, sexed, aged, weighed, and checked for reproductive status (currently breeding or not). Any dead animals were assigned a permanent catalog number and either preserved in 70% ethanol (shrews) or frozen (everything else). Collected specimens were sent to the Museum of Natural History at the University of Kansas (shrews in 1985) or to the Denver Museum of Natural History (all else) for permanent deposit and identification.

Mountain Chickadee Reproduction

To estimate nesting success (clutch size, fledgling rate, recruitment) of the mountain chickadee, a secondary cavity nesting species, observers installed 100 Schwegler nest boxes in each watershed in April (80 boxes) and October (20 boxes) 1985. Boxes were laid out in ten 4 x 5 grids, with 50-m spacing between boxes (fig. 1).

Table 1.--Mean values of vegetation attributes at vertebrate sampling stations[1] on the Coon Creek and East Fork watersheds.

Characteristic	Coon Creek	East Fork	Significance[2]
Basal area (m^2/ha)			
Lodgepole pine	17.4	16.5	N.S.
Engelmann spruce	7.1	8.9	N.S.
Subalpine fir	8.3	9.1	N.S.
Old growth score	35.1	36.6	N.S.
Canopy cover (%)	67.8	64.9	N.S.
Ave. tree height (m)	19.9	20.5	N.S.
Ave. d.b.h. (cm)	31.6	33.9	*
Snags/0.04-ha plot	1.9	2.0	N.S.
Percent cover			
Vegetation <2.0 m tall	47.7	46.4	N.S.
Forbs	9.4	10.8	N.S.
Grasses	8.5	13.1	N.S.
Rock	5.6	1.7	***
Litter	79.4	81.1	N.S.
Bare Ground	1.3	1.3	N.S.
Hard logs/0.04 ha plot	3.0	1.5	***
Soft logs/0.04 ha plot	12.9	9.4	***
Cosine aspect	0.0	-0.1	N.S.
Slope (%)	24.2	24.7	N.S.
Stream proximity[3]	0.39	0.3	N.S.

[1]N = 90 stations per watershed.

[2]T-test results: N.S. = $P>0.05$, *** = $P<0.001$.

[3]Proportion of stations within 100 m of a permanent stream.

Boxes were checked at weekly intervals throughout the nesting period each year. If a nest was found, that box was checked more frequently until all young had fledged. Eggs and young were counted, and adults and young were weighed, measured, and banded with No. 0 Fish and Wildlife aluminum bands.

Marten Movements

The purpose of this study is to describe patterns of movement and habitat selection by marten before, during, and after timber harvest. Marten were trapped using up to 60 Tomahawk No. 205 livetraps placed intermittently throughout the study area. Traps were checked daily for periods ranging from 3-10 days, and were baited with cat food, meat scraps, feather lures, or fish.

Captured marten were sedated using an intramuscular injection of ketamine (0.05 cc/kg body weight), measured, weighed, and sexed. A permanent number was tattooed on the inside of the cheek, and a radio telemetry collar (various configurations) was fitted around the animal's neck. Each animal was retained inside the trap until recovery from the sedative was complete (usually 40 min). Collared marten were relocated twice per week from a fixed-wing aircraft.

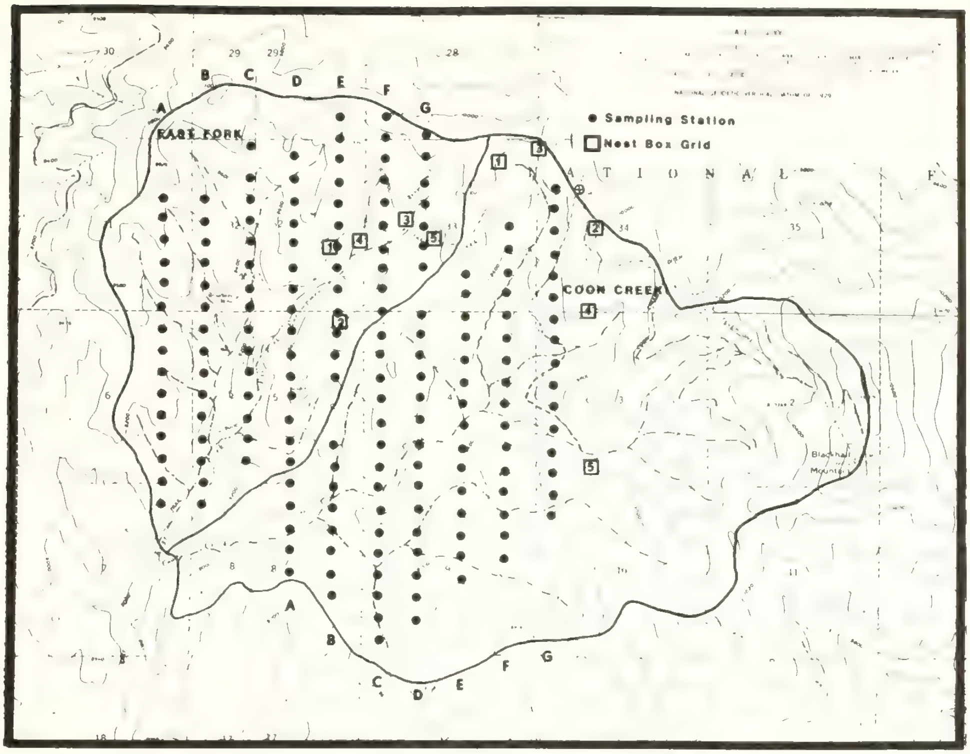

Figure 1.--Map of study area showing the Coon Creek and East Fork watersheds, sampling stations, and nest box grids.

Results

Vegetation

Vegetation characteristics were similar between the two watersheds (table 1). A discriminant analysis comparing mean values of basal area, d.b.h., height, canopy cover, and old growth score between the two watersheds was not significant (Chi-square = 10.3, DF = 7, P = 0.17). Slope, aspect, and stream proximity were also similar between the two watersheds (table 1).

Bird Community Structure

Observers sampled 41 bird species over both watersheds based on a total count of 14,897 observations. We observed 37 species on the Coon Creek watershed and 36 on the East Fork watershed. Those species that did not occur on both watersheds were rare (< 10 observations, total) and thus their occurrence on only one watershed was probably a matter of chance. Most species were equally abundant on the two watersheds, but 4 species (common raven, red-breasted nuthatch, mountain chickadee, ruby-crowned kinglet) were significantly more abundant on the East Fork and two (Clark's nutcracker, western flycatcher) were more abundant on Coon Creek (t - test, P < 0.05).

The mean abundance of six species differed significantly (P < 0.05) among the three primary timber types delineated on Stage II timber maps by Forest personnel (table 2). For those cases, the spruce-fir sawtimber type supported the greatest density, and as a result, also supported the greatest total density of birds (table 2).

Small Mammal Community Structure

We recorded at least 13 species of small mammals, all of which occurred on each watershed. We captured 2,428 individual animals during a total of 54,000 trap nights and recorded 755 observations of red squirrels during the bird counts (table 3). The most abundant small mammal was Gapper's Red-backed Mouse (1,203 individuals) followed by shrews (788) and Deer Mouse (131). The mean capture rate of shrews, Gapper's red-backed mouse, and western jumping mouse differed significantly among timber types, and all of these species were most abundant in the spruce-fir sawtimber sites (table 3). Mean capture rate of Gapper's red-backed mouse was greater in the Coon Creek watershed and the capture rate of the deer mouse was greater in the East Fork watershed; all other species were captured at nearly equal rates on the two watersheds.

Ecological Indicator Species

Several of the birds and mammal species studied are listed as ecological indicators by the Medicine Bow National Forest

Table 2.--Mean density (birds/100 ha) of birds among timber types on Coon Creek and East Fork watersheds, 1985-1986.

Bird species	Timber type: Lodgepole pine pole (n = 36)	Lodgepole pine sawtimber (n = 76)	Spruce/fir sawtimber (n = 59)
Sharp-shinned hawk Accipiter striatus	0	+	0
Cooper hawk Accipiter cooperii	+	0	+
Northern Goshawk Accipiter gentilis	+	0	0
Red-tailed Hawk Buteo jamaicensis	0	+	+
Northern Pygmy-Owl Glaucidium gnoma	+	0	0
Boreal Owl Aegolius funereus	0	0	+
Broad-tailed Hummingbird Selasphorus platycercus	7	11	8
Williamson's Sapsucker Sphyrapicus thyroideus	1	4	4
Downy Woodpecker Picoides pubescens	0	+	+
Hairy Woodpecker Picoides villosus	+	+	+
Three-toed Woodpecker Picoides tridactylus	+	1	2
Northern Flicker Colaptes auratus	1	1	1
Olive-sided Flycatcher Contopus borealis	0	+	+
Western Wood-Pewee Contopus sordidulus	0	0	+
Western Flycatcher Empidonax difficilis	3	3	6
Gray Jay Perisoreus canadensis	35	32	39
Clark's Nutcracker Nucifraga columbiana	1	2	1
Common Raven Corvus corax	+	2	11
Mountain Chickadee Parus gambeli	50	52	63
Red-breasted Nuthatch Sitta canadensis	2	2	2
Brown Creeper Certhia americana	8ab	9a	16b
American Dipper Cinclus mexicanus	0	0	+
Golden-crowned Kinglet Regulus satrapa	29a	33a	69b
Rudy-crowned Kinglet Regulus calendula	49	44	50
Mountain Bluebird Sialia currucoides	0	+	0
Townsend's Solitaire Myadestes townsendi	+	2	+
Swainson's Thrush Catharus ustulatus	2ab	1b	3a
Hermit Thrush Catharus guttatus	21	22	25
American Robin Turdus migratorius	52a	50a	68b
Warbling Vireo Vireo gilvus	+	0	+
Yellow-rumped Warbler Dendroica coronata	198	200	196
Wilson's Warbler Wilsonia pusilla	0	0	+
Chipping Sparrow Spizella passerina	+	+	+
Lincoln's Sparrow Melospiza lincolnii	7a	3a	19b
Dark-eyed Junco Junco hyemalis	143	153	164
Pine Grosbeak Pinicola enucleator	11	13	15
Cassin's Finch Carpodacus cassinii	4	4	4
Red Crossbill Loxia curvirostra	13	22	15
White-winged Crossbill Loxia leucoptera	0	+	0
Pine Siskin Carduelis pinus	70a	70a	90b
Evening Grosbeak Coccothraustes vespertinus	+	+	+
Total density	710a	738a	864b

[1]Pairs of means with same superscript letter did not differ significantly (Duncan multiple-range test, $P < 0.05$). Superscripts were not included if none of the means differed significantly.

[2]+ indicates mean density <1 bird/100 ha.

Table 3.-- Small mammal capture rates on the Coon Creek and East Fork watersheds, 1985-86.

Species	No. captured	Mean capture rate (N/300 trapnights)[1]: Lodgepole pine pole	Lodgepole pine sawtimber	Spruce/fir sawtimber
Shrews[2] (Sorex spp.)	788	2.72[a]	3.87[a]	6.09[b]
Water Shrew (Sorex palustris)	7	0	0.08	0.02
Least Chipmunk (Eutamias minimus)	46	0.42	0.14	0.33
Uinta Chipmunk (Eutamias umbrinus)	104	0.69	0.67	0.39
Golden-mantled Ground Squirrel (Spermophilus lateralis)	7	0.06	0.05	0.02
Red Squirrel[3] (Tamiasciurus hudsonicus)	7	60.4	46.0	0.2
Deer Mouse (Peromyscus maniculatus)	131	0.58	0.71	0.63

(continued)

Table 3.--(continued).

Species	No. captured	Mean capture rate (N/300 trapnights)[1] Lodgepole pine pole	sawtimber	Spruce/fir sawtimber
Gapper's Red-backed Mouse (Clethrionomys gapperi)	1,203	4.86[a]	6.01[ab]	8.37[b]
Heather Vole (Phenacomys intermedius)	2	0	0.03	0
Montane Vole (Microtus montanus)	14	0.06	0.07	0.08
Long-tailed Vole (Microtus longicaudus)	6	0	0.04	0.05
Western Jumping Mouse (Zapus princeps)	78	0.03[a]	0.42[ab]	0.69[b]
Ermine (Mustela erminea)	5	0	0.04	0.02

[1]See footnote 1, table 2, for explanation of letter superscripts.

[2]Identification pending analysis by taxonomic experts.

[3]Results presented for counts made during bird censuses and are expressed as number/100 ha.

(table 4). Three are indicators of late seral vegetation, but only one of these, Gapper's red-backed mouse, was actually more abundant in stands rated most highly for old-growth conditions (fig. 2). Two species are listed as indicators of early seral conditions. One of these was too rare to assess adequately; the other (western jumping mouse) was most abundant in wet, grassy habitats but occurred in both late and early seral stages and was most abundant at sites with large-diameter, tall trees (table 4).

Mountain Chickadee Reproduction

Of the 160 nest boxes available to chickadees during each of two nesting seasons, only four were used each year. Each of these eight nests was 100% successful. Observers banded all

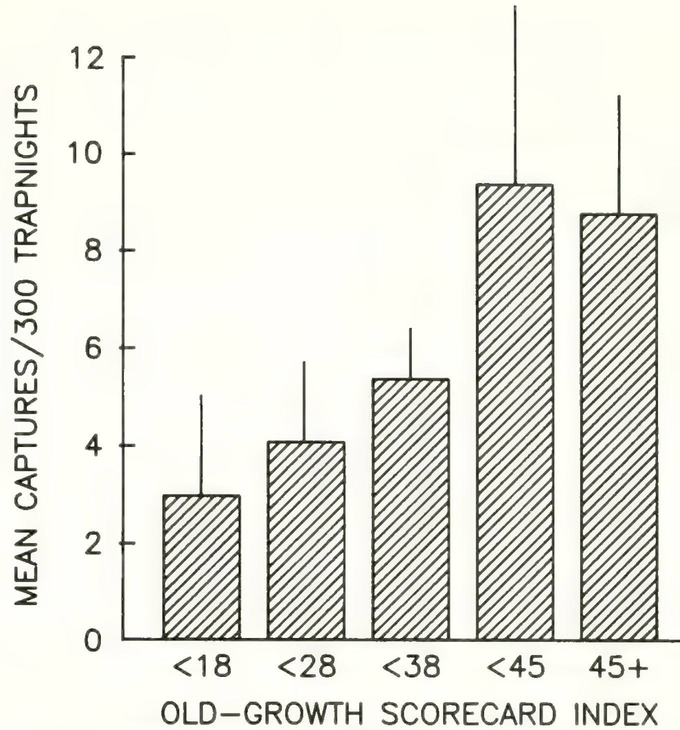

Figure 2.--Relative abundance (mean capture rate) of southern red-backed vole in relation to old-growth scorecard value. Vertical lines indicate upper 95% confidence of means.

but one adult and one nestling associated with nests. Low use of nest boxes during the first years following installation has been reported by other researchers (Brawn and Balda 1983); occupancy is expected to rise in succeeding years. However, an additional 180 boxes were added, one at each vertebrate sampling station, to increase box availability and create a more dispersed distribution of boxes.

Pine Marten Movements

During the period from 30 May 1985 through 30 April 1987, observers captured 23 marten and fitted radio telemetry

Table 4.--Correlations[1] of habitat characteristics associated with abundance of ecological indicator species (USDA 1985) sampled in community studies, 1985-1986.

Ecological indicator species	Old-growth score[2]	Stream presence	Basal area pine	spruce	fir	d.b.h.	Height
Gapper's Red-backed Mouse[3]	0.27	0.24	-0.50	0.42	0.28	0.24	0.38
Long-tailed Vole[4]							
Western Jumping Mouse[4]		0.39	-0.22	0.27		0.25	0.30
Hairy Woodpecker[3]							
Ruby-crowned Kinglet[3]					0.20		

[1]Pearson correlation coefficients are listed in table. Only significant ($P < 0.05$, n = 167) values are listed.

[2]Numerical scorecard rating of old growth conditions, as determined by Medicine Bow National Forest personnel.

[3]Indicator of late-seral conifer vegetation.

[4]Indicator of early seral vegetation.

collars on 20 of them. These animals have been relocated from 1 to 69 times for a total of 521 locations of all collared animals. The distribution of some of some of these animals is illustrated in figure 3.

Conclusion

All of these results are preliminary but they show that, in general, the vegetation structure and vertebrate community of the two watersheds are quite similar. Thus, these watersheds seem to be ideal for the longer term comparative study before, during, and after timber harvest. A number of species reach peak abundance in mature conifer sites, and these species are most likely to decline as timber is harvested. The greatest unknowns at present are (1) which species will benefit from the creation of early seral habitats, and (2) whether fragmentation of the Coon Creek watershed will result in unpredicted changes in abundance of species favoring late-seral stages.

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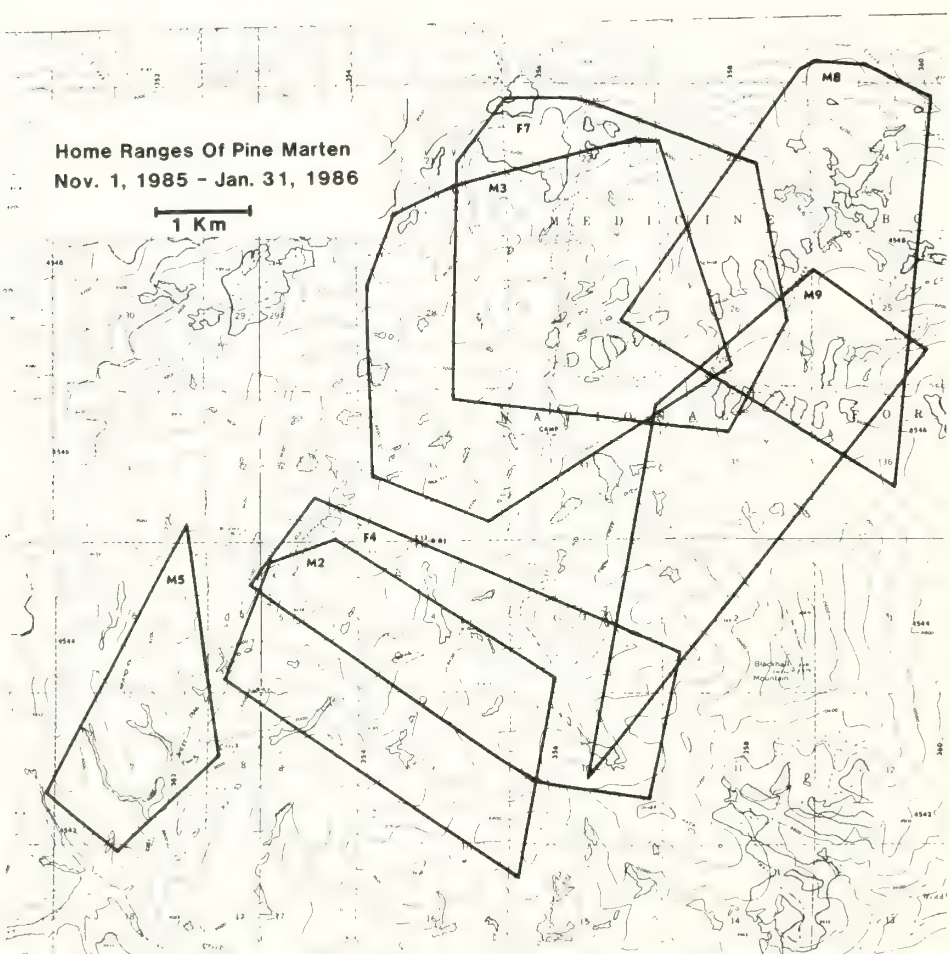

Figure 3.--Distribution of marten, November-January 1985/86 in vicinity of Coon Creek study area.

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Growth Efficiency, Leaf Area, and Sapwood Volume in Subalpine Conifers

Michael G. Ryan[1]

Abstract--Growth efficiency (stemwood produced per unit leaf area) estimates the ability of a tree to convert light energy into wood, and indicates carbon allocation processes. Maintenance respiration of woody tissues may cause observed patterns in growth efficiency decline in subalpine conifers.

Carbon fixed in photosynthesis provides the raw material not only for stem growth, but also for growth of leaves, branches, coarse and fine roots, and for the maintenance of living tissue (Kaufmann et al., this volume). However, not all tree parts have an equal chance of receiving this newly fixed carbon--maintenance of living tissue and the growth of fine roots and leaves have a higher priority than stem growth (Waring and Schlesinger 1985). The amount of carbon fixed, though, is related to the amount of leaf area (Linder 1985), the productive machinery of the tree. Since stemwood production has a low priority for fixed carbon, it can be a sensitive measure of the use of carbon by other tree parts. Therefore, growth efficiency (stemwood production per unit of leaf area) can indicate changes in the pattern of carbon allocation within the tree (Waring 1983).

Growth efficiency declines with increased tree age much faster for lodgepole pine (*Pinus contorta* var *latifolia* Engelm.) than for Engelmann spruce (*Picea engelmannii* Parry or subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) in Colorado subalpine forests (Kaufmann and Ryan 1987). Because growth efficiency can be an indicator of carbon allocation, the more rapid decline of growth efficiency for lodgepole pine compared with the other conifers suggests that carbon allocation patterns vary with tree size, species, and shade tolerance.

The change in growth efficiency patterns for these conifers over time may be related to changes in the balance between photosynthetic and respiring tissue. These tree species differ in the amount of leaf area supported per unit of conducting sapwood area, with lodgepole pine supporting much less leaf area than the other two conifers (Kaufmann and Troendle 1981). Since the sapwood of these species contains about 6% live parenchyma ray cells (Panshin and de Zeeuw 1970) and the volume of sapwood increases considerably with tree size, sapwood volume may be a reasonable predictor of maintenance respiration demand. Since photosynthesis per unit of leaf area is similar for the three species (Smith 1985), carbon assimilation should be proportional to leaf area. Therefore, trees in species with a low ratio of leaf area to sapwood should have a much greater relative respiratory loss of carbon than trees of species with a high ratio of leaf area to sapwood area. Differences in maintenance respiration should change the carbon available for stem growth and therefore change growth efficiency.

The objectives of this paper are (1) to present some background information on stem respiration in trees, (2) to examine evidence which suggests that maintenance respiration of woody tissues, particularly sapwood, increases as trees grow larger, and (3) to propose reasonable tests of the hypothesis.

Background

Respiration can be divided into two functional components: construction (growth) respiration and maintenance respiration (McCree 1970). Growth respiration refers to CO_2 evolution from processes generating energy for the synthesis of plant dry matter. Maintenance respiration is the CO_2 evolution from maintenance processes within the cell including protein turnover, the maintenance of ion and metabolite gradients (including membrane integrity), and physiological acclimation to a changing environment (Penning de Vries 1975). While the two processes may produce distinct end products, the carbon dioxide evolved is not biochemically distinct.

Growth respiration is proportional to the growth increment (dW/dt), while maintenance respiration is a function of the mass of living tissue (W) and temperature (T). Total respiration may then be expressed as:

$$R = a * dW/dt + b * f(W, T) \quad [1]$$

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where a and b are partitioning coefficients (Landsberg 1986). Growth respiration is independent of temperature, while maintenance respiration increases exponentially with temperature (Landsberg 1986).

Maintenance respiration may be very important for trees because of the large amount of respiring biomass in the stem, roots, and branches, and the sensitivity of this process to temperature. Because maintenance respiration is sensitive to temperature and tree size, knowledge of respiration can help explain differences in tree growth among the widely varying sites in the subalpine. Additionally, information about maintenance respiration should be useful in predicting the results of regional climatic changes on tree growth and species composition.

Stem and branch respiration is an important component in the carbon balance of trees, but has received little attention. However, a few studies have shown that respiration by woody tissues utilizes a large fraction of the annual photosynthetic production, particularly for larger trees. For example, Benecke and Nordmeyer (1982) estimated that 23% of annual production was respired by stems in a 40-year-old subalpine lodgepole pine stand. In contrast, smaller trees use less carbon for maintenance respiration. Stem respiration used 7% and branch respiration used 28% of annual photosynthetic production in a 14-year-old loblolly pine stand (Kinerson 1975). Linder and Troeng (1981) found that 5% of annual production was used for stem and branch respiration of a 20-year-old Scots pine tree. Because the annual carbon balance is difficult to quantify, these estimates suggest only the magnitude of the respiration fraction, and do not separate growth and maintenance respiration.

Stem respiration, then, can be an important component of the tree's carbon balance, and our knowledge of stem respiration is limited. Separation of stem respiration into growth and maintenance components may aid in understanding tree growth patterns, because of the sensitivity of the maintenance component to temperature. Little is known about the magnitude of these two components, the contribution from various tissues, and changes in carbon allocation to growth and maintenance respiration of stems with stand development.

Observations from Current Research

My research is focused on exploring patterns in carbon allocation for subalpine conifers and examining the impact of maintenance respiration on growth efficiency. In addition to the work on growth efficiency and age presented in Kaufmann and Ryan (1987), I have explored the question of growth efficiency decline using several approaches. These include (1) examining patterns of leaf area and sapwood volume development for subalpine conifers, (2) studying patterns in growth efficiency for lodgepole pine growing under two different temperature regimes, and (3) comparing growth efficiency of similar species in very different climatic regimes. These preliminary results suggest that the observed patterns in growth

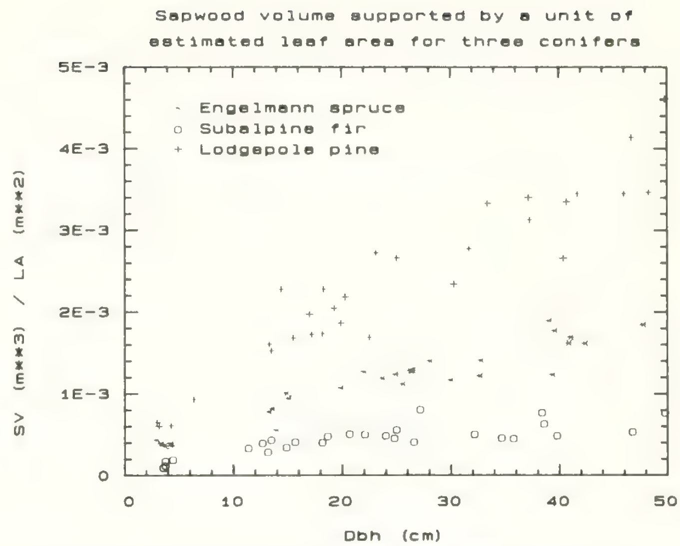

Figure 1.--Actual sapwood volume supported (SV) by a unit of estimated leaf area (LA) for three subalpine conifers as a function of diameter (d.b.h.).

efficiency may be related to maintenance respiration of woody tissues (particularly sapwood).

Leaf Area and Sapwood Volume Development

I measured sapwood volume on 30 trees each of lodgepole pine, Engelmann spruce, and subalpine fir, using stem sections and standard mensurational techniques for volume determination.[2] For each of the sample trees, leaf area was estimated from equations given in Kaufmann and Troendle (1981). The ratio of actual sapwood volume to estimated leaf area increased much more rapidly with tree size for lodgepole pine than for spruce or fir (fig. 1). If carbon assimilation is proportional to leaf area, then the use of carbon by sapwood in maintenance respiration increases with the ratio of sapwood volume to leaf area. Therefore, lodgepole pine should show the strongest decline in growth efficiency with increasing tree size, since it should have the largest demand for maintenance respiration.

Sapwood volume equations[2] were used to estimate sapwood volume for the data presented in Kaufmann and Ryan (1987). Volume growth and sapwood volume were both divided by estimated leaf area to reference these variables to a comparable level of productive capacity. Although I believe that a reasonable interpretation of the data is possible using such an approach, autocorrelation may complicate interpretation of the resultant patterns.

Plots of growth efficiency (volume growth per unit estimated leaf area) versus sapwood volume per unit estimated leaf area show a strong negative relationship for lodgepole pine, and a constant growth efficiency for spruce and fir (figs.

[2]Ryan, M. G. 1987. Sapwood volume equations for three subalpine conifers. Manuscript in preparation.

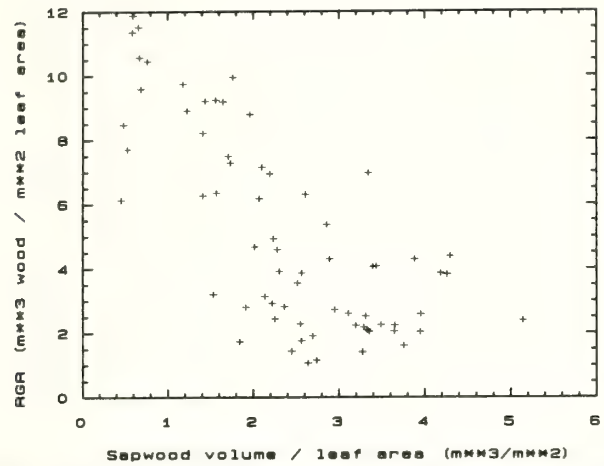

Figure 2a.--Growth efficiency (RGR, volume growth per unit of estimated leaf area) versus sapwood volume supported per unit leaf area for lodgepole pine.

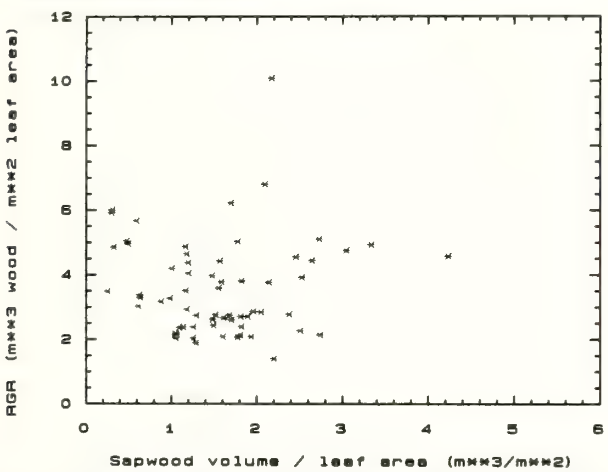

Figure 2b.--Growth efficiency (RGR, volume growth per unit of estimated leaf area) versus sapwood volume supported per unit leaf area for Engelmann spruce.

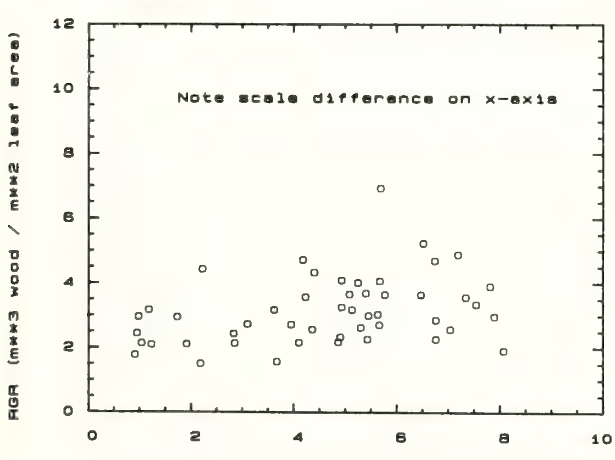

Figure 2c.--Growth efficiency (RGR, volume growth per unit of estimated leaf area) versus sapwood volume supported per unit leaf area for subalpine fir.

2a, 2b, 2c). These patterns indicate that relative growth rate may be related to sapwood volume for lodgepole pine, and that the pattern of growth efficiency decline is consistent with the relationships presented in figure 1.

Growth Efficiency Decline Under Two Temperature Regimes

I examined the relationship between growth efficiency, leaf area, and sapwood volume for lodgepole pine stands of different ages growing at two different elevations.[3] Even-aged stands of 40, 60, and 240 years in age were sampled at 2,800 m in elevation, and stands of 40, 75, and 240 years in age were sampled at an elevation of 3,200 m. All other physiographic characteristics were similar for the 6 stands: slopes were less than 10%, aspects were between 315 and 360 degrees, and *Vaccinium scoparium* was the dominant understory plant. Additionally, stand factors (basal area, leaf area, crown competition, stems per hectare) were similar among all stands. Of course, these stand factors changed somewhat with stand age, in response to normal growth.

These stands should have an average temperature regime that differs by 4 C, based on the dry adiabatic lapse rate applied to the 400-m elevation difference. Since maintenance respiration for a given live biomass is strictly a function of temperature (Landsberg 1986), the carbon used in maintenance respiration should be lower for the cooler (high elevation) stands. Because the 3,200-m stands use less carbon for respiration, growth efficiency should decline less rapidly than for the 2,800-m stands, if carbon assimilation and fine-root turnover remain constant.

The rate of decline in growth efficiency for these stands appears to be related to sapwood volume (fig. 3), but there is no difference with elevation. Actual measurements at the sites confirm the 4 C difference in temperature during the growing season. The lack of difference in growth efficiency decline between elevations suggests that there may be compensating mechanisms in carbon allocation processes. Both carbon assimilation and fine-root turnover may offset changes in maintenance respiration demand. Much more work is needed to characterize the carbon budget for these stands.

Growth Efficiency Decline in Two Regions

I compared growth efficiency for aspen and lodgepole pine stands growing in Colorado with stands of aspen and jack pine (a species very similar to lodgepole) growing in the north-central United States. These two locations doubtless have many differences, but the major differences are likely to be the length of the growing season and the temperature regime

[3]Ryan, M. G. Leaf area and sapwood volume development in subalpine lodgepole stands: the relationship between carbon production and consumption. Manuscript in preparation.

during the growing season. The Colorado sites are characterized by shorter growing seasons and cooler night temperatures.

A yield-table program for even-aged stands in the Rocky mountains (RMYLD, Edminster (1978)) was used to estimate stem volume growth for stands of aspen and lodgepole pine. The simulations were run using a site index of 21 m/80 y and "non-limiting" conditions; that is, I chose a relatively low density (740 per ha) stocking level so that trees were free to grow, and predicted density dependent mortality was minimized. Aspen volume growth for the north-central states was calculated from yield tables given in Perla (1977) using a site index of 21 m/50 y. Volume growth for jack pine in the north-central states was calculated from information in Benzie (1977). Leaf area was calculated from basal area using equations in Kaufmann et al. (1982); leaf area for jack pine was calculated using lodgepole pine equations. Nine 10-year projection periods were used for RMYLD simulations and six 10-year projection periods were used from the north-central yield tables.

These regions have very different productive capabilities (based on site index), with the north-central sites having a much higher potential growth. Since the productive capabilities are so different between the regions, I could not model stand growth using the same site indices. Therefore, I selected the site indices of 21 m/80 y for the Rocky Mountains and 21 m/50 y for the north central because they represented very productive sites relative to others in the region.

Growth efficiency declines much more rapidly for stands in the north-central United States than in the Rocky Mountain region (fig. 4). The difference in productive capacity is very evident for the aspen stand, but production rapidly approaches that found in the Rocky Mountains as the living biomass increases. Relative growth rate for jack pine in the north central is initially similar to that in the Rocky Mountains but it declines more rapidly.

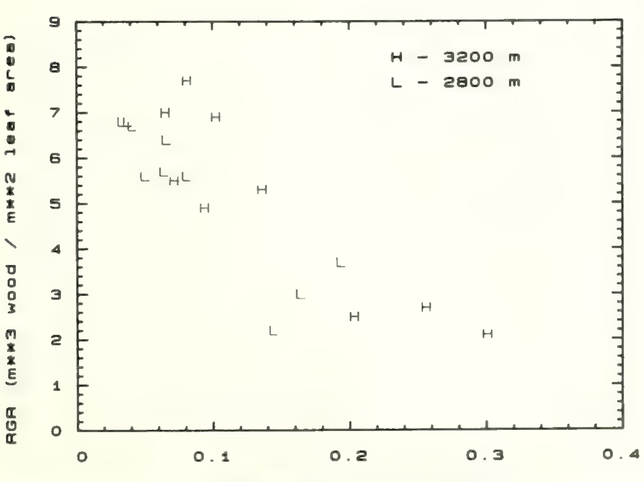

Figure 3.--Mean growth efficiency per tree versus sapwood volume for 6 lodgepole pine stands (3 plots per stand) at two elevations.

Additionally, there are pronounced differences in longevity between the two regions. Aspen in the north central states rarely lives beyond 60 years, while the life expectancy in the Colorado Rockies is almost double that. Since one of the major environmental differences between these sites is the warmer temperatures of the north-central site, maintenance respiration could explain these differences.

Conclusions and Recommendations

These preliminary observations indicate that carbon allocation patterns vary widely among subalpine conifers. Maintenance respiration of woody tissues may explain the observed patterns of growth efficiency and carbon allocation, but additional work is needed to fully understand the processes. The hypothesis that maintenance respiration of woody tissues accounts for an ever-increasing share of the tree's carbon as the tree grows should be tested directly by: (1) estimating growth and maintenance respiration of various woody tissues and relating respiration to live cell content, and (2) predicting growth efficiency patterns for stands from information on leaf area and sapwood volume development--then comparing these predictions to field measurements. Work with maintenance respiration may allow us to predict the effects of large scale temperature changes on tree growth and longevity.

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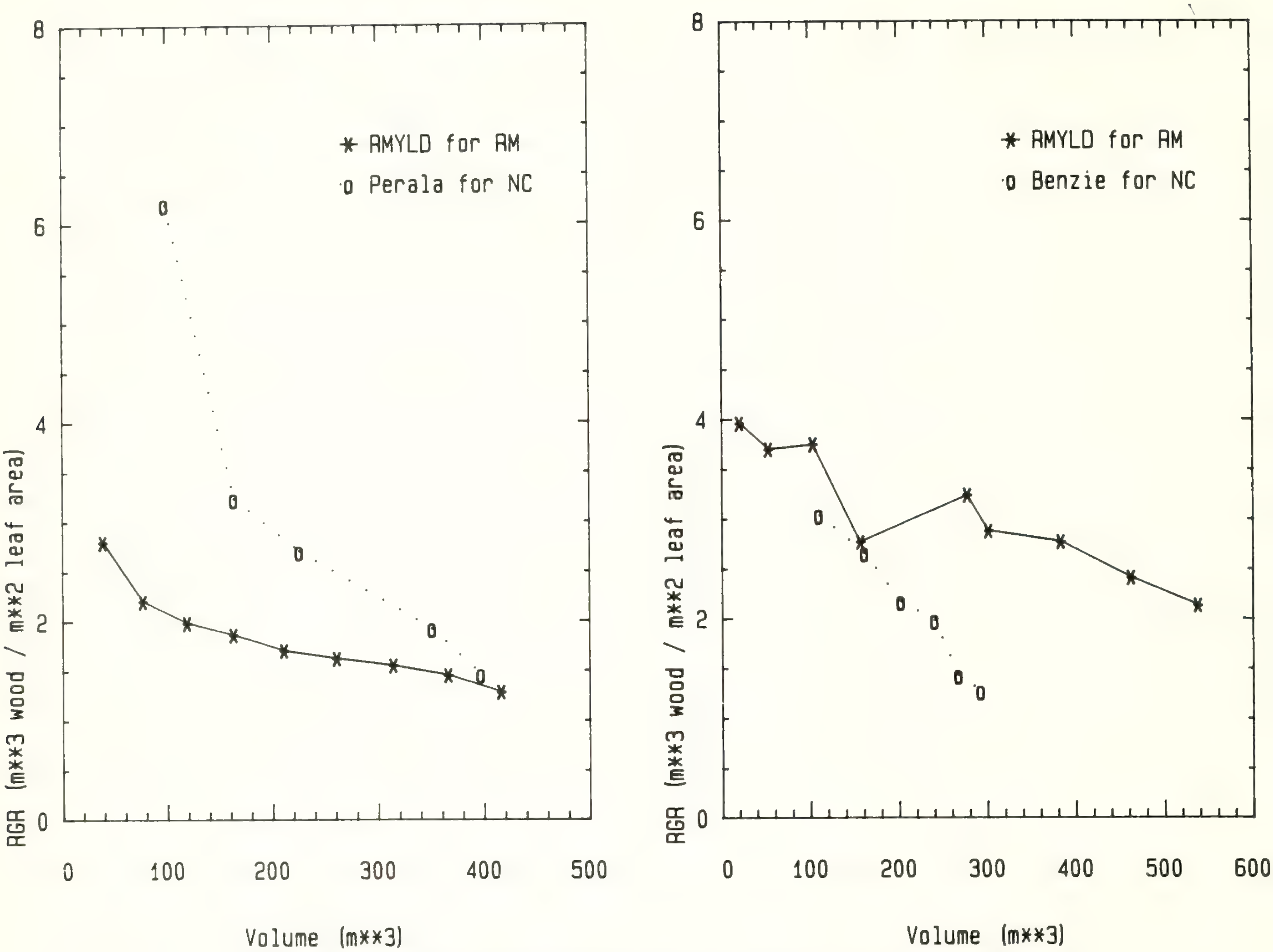

Figure 4.--Growth efficiency versus stand volume for aspen in the Rocky Mountains and aspen in the north-central states and for lodgepole pine in the Rocky Mountains and jack pine in the north central states.

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Observations of Oversnow Flow in Subalpine Meadows of Colorado

Richard Kattelmann[1]

Abstract--Oversnow flow occurs when snowmelt runoff saturates snowpacks and results in formation of channels at the snow surface. Where these channels extend through the snowpack to the soil surface, localized soil erosion may be much greater than commonly expected under snowmelt conditions. Oversnow flow and associated soil erosion were observed at several locations in Colorado.

Oversnow Flow

Snowmelt percolates through the unsaturated bulk of the snowpack to a saturated zone overlying the soil surface. Snowmelt water may then infiltrate into the soil or travel downslope over the soil, where it accumulates the contributions of other portions of the snow cover. Water flowing downslope both through and over the soil concentrates in topographic depressions and eventually in small stream channels. Where midwinter streamflow is too low to maintain an open channel, the stream channels are usually blocked by ice and snow at the onset of spring snowmelt. If the melt rate increases gradually, then the permeability of the ice and snow in the channels may increase quickly enough to accommodate the increasing flows. Over time, the ice and snow melt from frictional heating, and the channel opens up under the snow.

Alternatively, the permeability of ice and snow in the channels and any open channel capacity may be insufficient to pass all of the runoff generated by rapid snowmelt. The saturated volume of the snowpack around the stream channel increases until all of the water received at a point can be transported downstream. In many cases, a balance in flow is not reached until the entire depth of the snowpack is saturated. When the water table reaches the snow surface, water begins to flow freely downhill as oversnow flow.

This open channel flow confined by saturated snow can be termed oversnow flow. It appears to be a highly localized and transitory phenomenon occurring only under certain combinations of snowpack, meteorologic, and topographic conditions. But it can be important locally because of its ability to increase peak streamflows and sediment delivery (Sturges 1975). Oversnow flow occurs where water inputs to the snowpack in a topographic depression exceed the capabilities of undersnow stream channels and Darcian flow through the snowpack to transport water downslope. It may be considered analogous to saturation overland flow (Sturges 1975). A special type of oversnow flow occurs when a stream is suddenly blocked and water flows over unsaturated snow for a few minutes before infiltrating into the snow cover.[2]

Oversnow flow has been described in detail for the big sagebrush country of south-central Wyoming (Sturges 1975) and mentioned in relation to lake overflow and channel development during spring breakup in the High Arctic (e.g., Woo 1980, Woo and Sauriol 1980) and Antarctic (Birnie and Gordon 1980). Otherwise, only a few topics related to saturated snow appear in the hydrology literature. Fully-saturated snowpacks have been noted in subarctic Quebec (Granberg 1979). Macropores in snow have been identified as open conduits within snowpacks which permit rapid drainage of saturated zones (Kattelmann 1985). Supraglacial streams occur on the firn and ice of temperate glaciers and have been studied in relation to channel development processes (e.g., Dozier 1976, Knighton 1981, Parker 1975).

Saturation of snow with water can result in slushflows when an entire mass of slush is set in motion (Washburn and Goldthwaite 1958). They are a common feature of northern latitudes (e.g., Luckman 1977, Nyberg 1985, Onesti 1985) and a serious hazard in Norway (Hestnes 1985). Many slushflows probably begin where oversnow flow is occurring. While saturated snow is known to have inherently low strength, not all slush accumulations become slushflows. Slushflows have great erosive power (Nyberg 1985) and can be a very effective geomorphic agent (Luckman 1977).

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[2]Brandow, C. 1987. personal communication. California Department of Water Resources, Sacramento.

This paper describes observations of oversnow flow in subalpine meadows of central Colorado during two spring melt periods and suggests possible consequences of such flow.

Field Observations

The primary study area was at Shrine Pass (3350 m elevation) near Vail Pass on Interstate Highway 70. Near the pass, Turkey Creek begins in a meadow with a slope of 2° to 3° to the north-northwest, and West Tenmile Creek begins in a meadow with similar slope on the south side. The snowpack is usually about 1 to 2 m deep at the typical onset of melt in mid-May. Streamflow is measured by the U.S. Geological Survey in both streams, but the gaging stations are located too far downstream to reveal anything about flow conditions in the headwaters. Oversnow flow was also observed at the study site on June 3 and 16-17, 1979 and in mid-June, 1980, as well as near Loveland Pass (3650 m), Trail Ridge (3700 m), Tennessee Pass (3200 m), and Independence Pass (3700 m) in June and July 1979. Such flow has also been seen by the author on numerous occasions in the Sierra Nevada of California.

Oversnow channels commonly began in zones of obviously saturated snow 3 to 7 m across. The channels took form 5 to 20 m downslope of the uppermost saturated snow (fig. 1). The snow channels ranged from 10 to 150 m long before the water entered an exposed stream channel. All incised channels observed in Colorado were from 0.2 to 0.8 m wide and 0.3 to 1 m deep. The form of the channels changed markedly over the course of a day as the channels adjusted to changing discharge and alternate erosion and clogging with displaced snow. The channels tended to meander except where they became deeply incised. These snow channels were not always found directly above their earthen counterparts.

Surface velocities of 0.1 to 0.6 m/s were measured. Estimated discharge in the surface channels at various points and times ranged from 0.01 to 0.1 m^3/s. Snowpits were excavated at 2-m intervals away from the stream to determine the depth and extent of saturated snow (fig. 2). On low-gradient sideslopes, saturated snow was found only a few centimeters below the snow surface and for more than 10 m away from the channels.

The bed of the incised channels intermittently contacted the soil surface. Downstream of such points of contact were large accumulations of sediment (fig. 3). Occasionally, the water in a short reach was quite turbid. Sediment was deposited where snow channels ended because of the reduction in water velocity. Sediment was also found where oversnow flow ceased and water infiltrated into snow in areas that lacked large conduits or macropores.

Figure 1.--Oversnow flow channels begin in broad zones of saturated snow.

Possible Consequences of Oversnow Flow

Water flow through saturated snow has few external effects so long as it remains below two critical thresholds. At the extreme, if water accumulates to the point where the structural integrity of the snow mass is exceeded, then a slushflow is released. A less spectacular threshold is the saturation of the full depth of the snowpack where oversnow flow begins. At this point, resistance to flow decreases sharply and velocity increases. As the surface channel cuts into the snowpack through both mechanical and thermal erosion, more water drains into the channel from the sides, adding to the overall stream power.

The concentration of water in a highly efficient, low-friction channel results in great erosive potential wherever it reaches the underlying soil. Because of the rapidly changing nature of the snow channel, erosion can occur at several locations during the few days of intense oversnow flow. One factor that limits the duration of oversnow flow is breakup of the snowpack down to the soil surface. Extensive soil displacement was noted at the sites of oversnow flow observed in Colorado. Substantial bank cutting, very high suspended sediment concentrations, and thick channel deposits have been noted in connection with oversnow flow in Wyoming (Sturges 1975).

Erosion by oversnow flow usually occurs in meadows and along stream courses. Such areas are of special concern because they are sensitive to forest management activities. The occurrence of oversnow flow-induced erosion may help explain soil disturbance found to be in excess of what is normally expected under snowmelt runoff conditions. Knowledge of the potential effects of oversnow flow could also improve the effectiveness of meadow restoration, gully control, roaddrainage, and channel stability maintenance efforts.

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Figure 2.--Snowpits excavated below points of infiltration showed the extent of water-saturated snow.

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Figure 3.--The areas where the snow channels broke up and the water slowed down were covered by sediment deposits.

Stormflow Responses to Forest Treatments on Two Arizona Mixed Conifer Watersheds

Alden R. Hibbert and Gerald J. Gottfried[1]

Abstract--Forty years of hydrological records from the North and South Forks of Workman Creek were analyzed to estimate the effects of several treatments on stormflow volumes and peaks. Summer stormflows and peaks increased exponentially with size of storm after each treatment. Although percent changes were large, actual increases were very small. Winter stormflow increases were smaller on a percent basis but were larger in volume.

Water yield improvement has been the major emphasis of forest hydrology in the arid Southwest, where the demand is great for water. However, precipitation varies greatly from year to year and large amounts of runoff may be generated by individual storms. In recent years, several large winter storms have generated damaging floods which have raised fears of dam failures in the main valley population centers.

These events have created an interest in the effects of forest management practices on both winter and summer stormflow volumes and peak flow rates. It is well known that water yields can be increased by reducing forest cover (Rich and Gottfried 1976, Brown and et al. 1974, Baker 1986). However, it is not known if stormflows are increased proportionately to nonstorm (base) flows, since little work has been done on individual stormflows.

Mixed-conifer forests occupy 322,500 acres in Arizona, and approximately 2 million acres in the entire Southwest, including southwestern Colorado. The 40-year hydrological record on the Workman Creek watersheds provides an excellent opportunity to describe and analyze the effects of several forest management treatments on stormflow volumes and peak flow rates.

STUDY AREA

Workman Creek is within the Sierra Ancha Experimental Forest, approximately 30 miles north of Globe in central Arizona. The three experimental watersheds are North Fork (248 acres), Middle Fork (521 acres), and South Fork (318 acres). Elevations range from 6645 to 7789 ft.

The climate at Workman Creek is characterized by cold, moist winters; warm, dry springs and falls; and by warm, moist summers. The average annual precipitation at the recording rain gage in Middle Fork was (with standard error) 32.8 ± 1.5 inches from 1938 through 1981. Approximately two-thirds of the precipitation falls during the October to May winter period, usually as snow. Numerous, intense thunderstorms occur in a rainy season from July through September.

Perennial streamflow was recorded continuously at 90° V-notch weirs on North Fork and on South Fork and at a combination 90° V-notch and 7-foot Cipoletti weir at Main Dam on the main watershed below the confluence of the three watersheds. Control watershed (Middle Fork) streamflow was not gaged separately, but is calculated by substracting the South and North Fork values from the Main Dam streamflow (Rich and Gottfried 1976). Average annual runoff for the entire watershed at Main Dam prior to treatment in 1953, was 3.30 ± 0.69 inches. Mean runoff values for all three sub-watersheds were within 3% of the average for Main Dam.

Mixed-conifer stands of Douglas-fir *(Pseudotsuga menziesii)*, white fir *(Abies concolor)*, and ponderosa pine *(Pinus ponderosa)* originally occupied the more moist site, while almost pure ponderosa pine stands were found on drier sites. New Mexico locust *(Robinia neomexicana)* and Gambel oak *(Quercus gambelii)* were common understory trees. Average basal area was about 189 ft^2 per acre for all trees 1 inch d.b.h. and larger.

WORKMAN CREEK TREATMENTS

The Workman Creek watersheds were established in 1939 to determine the hydrology of mixed conifer forests and

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changes in streamflow and sedimentation caused by land management treatments. The objective on North Fork was to determine the potential for water yield improvement by removing the vegetation in a series of steps, and converting to a grass cover. The South Fork objective was to evaluate changes resulting from forest management activities. The sequence of treatments is presented in table 1. The treatments and their effects on annual and seasonal water yields are summarized below from Rich and Gottfried (1976).

South Fork

The first treatment in 1953 was a single-tree selection harvest, which, with roads, skid trails, and stand improvement work, reduced watershed basal area by 36%. In July 1957, a 60-acre wildfire in the upper end of South Fork destroyed another 9% of the original basal area. The harvest and burn (1954-66) resulted in a statistically significant water yield increase of 0.24 ± 0.20 inch (7 ± 6%); however, the increase was so small that it was considered insignificant from a practical point of view. No detectable water yield changes occurred after the 1957 wildfire, but Rich (1962) reported that all flood peaks for the first two summers were higher than expected; the largest storm peaked to 157 csm, twice the value of the previous high event.

A commercial harvest in 1966 removed most merchantable trees and thinned the remainder in an effort to convert the mixed conifer stand to ponderosa pine with a proposed final stand density of 40 ft²/acre, considered optimum for combined timber and water production. Unstocked areas were planted with ponderosa pine seedlings. This treatment, which affected 83% of watershed, resulted in an average annual water yield increase of 4.20 ± 1.08 inches (110 ± 29%) from 1967 through 1979.

North Fork

The first treatment in August 1953 was a riparian cut of broadleaved trees consisting of Arizona alder (*Alnus oblongifolia*) and big tooth maple (*Acer grandidentatum*) along streams, springs, and seeps. This treatment, which removed 0.6% of watershed basal area, did not produce a detectable increase in seasonal or annual runoff.

Nearly one-third (80 acres) of the watershed adjacent to the channel was cleared of its moist site forest of predominantly Douglas-fir and white fir by a timber harvest in 1958. The cleared area was seeded to grass. The moist site treatment (1959-66) increased water yields by 1.28 ± 0.28 inches (42 ± 10%), most of the increases occurring during the 8-month winter period.

The final North Fork treatment in 1966 converted 100 acres (40%) of dry-site merchantable ponderosa pine, upslope from the moist-site area, to grassland. Grasses were seeded, and New Mexico locust invaded the cleared sites, as occurred on the moist-site clearing. Streamflows from 1967 through 1979 increased 1.77 ± 2.99 inches (37 ± 45%) above those produced by the moist-site treatment. The combined moist- and dry-site treatments (1959-79) increased streamflow by 2.65 ± 0.80 inches (72 ± 22%).

DATA ANALYSIS

The hydrographs from 40 years of records (1940-1979) were reviewed for rain-generated-stormflow events 0.001 inch and larger, which occurred simultaneously on all three watersheds. Stormflow hydrographs were partitioned into stormflow and delayed flow components using the hydro-

Table 1.--Schedule of treatments for the Workman Creek watersheds.

Water years	Treatments				
	North Fork	No. of years	Middle Fork	South Fork	No. of years
1939-53	Calibration	15	Calibration	Calibration	15
1954-58	Riparian cut of broadleaf species	5	Control		
1954-56				Start of single-tree selection harvest	3
1957-58				Wildfire	2
1959-66	Convert moist site to grassland	8	Control	Interim period	8
1967-79	Convert dry site to grassland	13	Control	Commercial clearcut to convert to a pure ponderosa pine stand with a basal area of 40 ft./acre	13

graph separation technique developed by Hewlett and Hibbert (1967). Separation was arbitrarily determined by projecting a line of 0.05 csm/hr slope from the storm hydrograph rise to the recession limb. Peak flow rate is maximum hydrograph peak minus initial flow rate at rise of storm hydrograph.

The data were analyzed by winter (October-May) and summer (June-September) periods. Different techniques were used to evaluate the two periods. Changes in summer stormflows and peaks were determined by comparing the relationship between stormflow volume or peak and storm rainfall. Increases were calculated by comparing the regression coefficients of the pre- and posttreatment relationships. Exponential regression relationships were developed for each treatment period using log-transformed data to control variance. Regressions of the transformed data were significant ($P \leq .05$), with the r^2 values ranging from 0.27 to 0.54. The pre- and posttreatment regressions were compared in a covariance analysis using dummy values to separate treatment periods.

Winter events could not be analyzed by the runoff-precipitation relationship because of the variability caused by rain on snow, where the actual daily inputs of snowmelt into the channels were unknown. Winter stormflow volumes were analyzed by comparing before- and after-treatment linear regressions developed from paired events on treated and control watersheds. Regressions had r^2 values between 0.82 and 0.93. Two sets of regressions were developed: one for stormflow volumes up to 2.5 inches (2 large snowmelt-dominated stormflows between 4 and 8 inches were rejected as outliers), and the other for smaller stormflows of less than 0.5 inch. Posttreatment regressions were compared with the respective pretreatment regression, and a combined regression was then developed to describe the differences between the two relationships. Covariance analysis was used to compare the slope and intercept coefficients of the pre- and posttreatment regressions. The differential slope and intercept coefficients of the combined regression reflect this comparison. Differences in the slope coefficient indicate that a treatment has a multiplicative effect, where the dependent variable increases more rapidly than does the independent variable.

No analysis was made on winter peaks. The arrangement of weirs on Workman Creek, and the need to calculate Middle Fork (control watershed) values, makes it difficult to separate peak flows on Middle Fork from the peaks on the other two watersheds.

RESULTS

Summer Storms

Summer stormflows and peaks increased after each treatment compared with pretreatment levels, when storm rainfall is used as the independent variable in a log-transformed regression analysis (table 2). The increases were exponentially related to storm size (fig. 1) for storm rainfalls between 0.5 and 2.5 inches. Small storms of less than 0.5 inch were excluded from the analysis because of the large variability attributed to the spotty nature of storm coverage on the watersheds. Peak flow response curves are not shown, but were very similar to the stormflow curves in figure 1.

South Fork

The largest increases in summer stormflows and peaks over pretreatment conditions occurred on South Fork during the two summers after the 60-acre burn. Stormflow volumes increased from 2.5 to 3 times, and peaks increased from 5 to

Table 2.--Changes in summer stormflows and peaks after various treatments on Workman Creek watersheds.

Treatment	N	Stormflows				Peaks			
		At Ppt = 1 in.		At Ppt = 2 in.		At Ppt = 1 in.		At Ppt = 2 in.	
		Inches	%	*Inches*	%	*csm*	%	*csm*	%
South Fork									
Pretreatment	54	0.0023[1]	--	0.0079[1]	--	1.47[1]	--	3.97[1]	--
Single tree	26	0.0018	78	0.0177	223	0.7	49	4.0	102
60-acre burn	12	0.0062	264	0.0450	564	3.8	264	33.8	848
Postburn interim	52	-0.0003	-12	0.0039	49	-0.3	-22	0.4	10
Commercial	69	0.0021	90	0.0103	130	0.8	54	3.6	91
North Fork									
Pretreatment	54	0.0008[1]	--	0.0033[1]	--	0.51[1]	--	1.54[1]	--
Riparian	37	0.0007	92	0.0093	280	0.3	51	2.3	149
Moist site	52	0.0026	322	0.0150	442	1.6	304	6.4	411
Dry Site	69	0.0030	378	0.0125	378	1.5	299	4.8	307

[1]These are pretreatment means which are the basis for computing percent changes after treatment.

10 times above values recorded during the previous three years following the single-tree selection harvest. The harvest, however, also showed a substantial percentage increase of 223% over pretreatment level for 2 inches of rain (table 2, fig. 1), although the increase was only 0.018 inch of flow volume. After the first two postfire summers, stormflows and peaks returned to near pretreatment levels, and became nonsignificant for the next eight summers of the interim period (1959-66). Stormflows and peaks during the commercial harvest period (1967-1979) were less responsive to summer storms than during either the selection harvest or wildfire. An exception was for storms of less than 1.5 inches of rainfall, when the response was essentially the same as for single-tree selection harvest (fig. 1).

North Fork

The riparian cut increased summer stormflows and peaks during the 5-year posttreatment period by up to 280% (0.009 inch) at 2 inches of rainfall, even though no annual or seasonal runoff increases were detected for this treatment by previous investigators (Rich and Gottfried 1976). The moist-site cut, on 32% of the watershed next to the channel, increased summer stormflows and peaks from 322% to 442% (0.003 to 0.015 inch) over pretreatment levels for rains of 1 to 2 inches, or roughly twice as much as was caused by the riparian cut. After the dry-site cut on the upper slopes of North Fork, increases in stormflows and peaks dropped back slightly for storms greater than 1.5 inches, although they were still four or more times larger than expected without treatment (table 2, fig. 1).

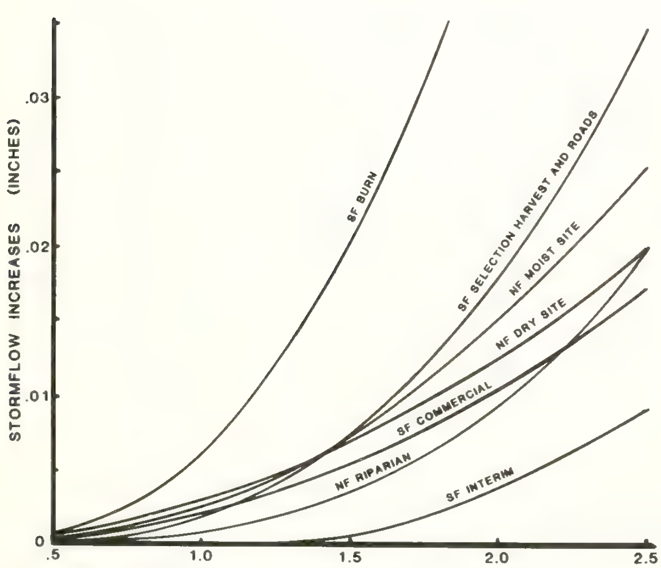

Figure 1.--Summer treatment response curves developed from differences between posttreatment and pretreatment stormflow regressions on storm rainfall.

Winter Storms

Winter stormflows responded less to treatment in terms of percent increase than did summer stormflows, although the actual flow volume increases were larger. Linear regressions using all data except 2 outliers indicated statistically significant increases in the differential slope coefficients for each treatment period (rows 1, 2, 5, 6 in table 3). Additional regressions were run on small storms only by limiting the range of control watershed stormflows to less than 0.5 inch (rows 3, 4, 7, 8 in table 3). The reason for classifying the data in this way was to examine the possibility of the increases being larger for small storms than for large storms, a trend indicated by a regression analysis of log transformed data.

The results were mixed: the largest increases in regression slope change for North Fork treatments were in the ≤0.5-inch stormflow range (rows 7 and 8, table 3). For the South Fork, a small nonsignificant decrease was indicated for the combined selection cut, burn, and interim period (row 3, table 3), and a marginally significant ($P = 0.06$) increase was shown for the commercial cut (row 4, table 3). The results are heavily influenced by small events because 75 to 87% of the stormflows were smaller than 0.5 inch. The lack of stormflow response in the first treatment period on South Fork (row 3, table 3) is consistent with earlier evaluations, which showed very little annual or seasonal increase from these treatments (Rich and Gottfried 1976). However, this lack of small stormflow response for the first treatment period on South Fork changes to a strong response when seven larger storms (0.5-2.5 inches) are added to the analysis (row 1, table 3). It is possible that, after treatment, South Fork was more responsive to larger storms than was North Fork. Predictions based on the 0-2.5 inches data set must be made with caution because of the disproportionate influence of the small number of storm events larger than 0.5 inch.

Winter stormflow volume increases (last columns in table 3) were calculated by taking the difference between posttreatment and pretreatment regressions evaluated at control watershed stormflow levels of 0.5 inch for the ≤0.5 inch data set, and 2 inches for the larger stormflow range. It is apparent that, while the percent increases are much less than for summer storms, the actual increases in stormflow volumes are much larger.

SUMMARY AND CONCLUSIONS

The changes in summer stormflows and peaks, which increased exponentially with storm rainfall after various treatments, indicate the sensitivity of the channels and channel-side environments to vegetation removal and soil disturbance. These increases in stormflows and peaks are largely attributed to decreased interception of rainfall caused by removal of the vegetation along the channels, and to more direct runoff into the channels from roads, skid trails, and from other disturbance, such as the wildfire.

Table 3.--Increases in winter stormflows after treatments on Workman Creek Watersheds.

Row	Treatment period	Number of paired events	Range in control watershed stormflow	Linear Regression Coefficients: Differential intercept			Differential slope			Calculated increase[1]	
			Inches	Inches	%	P value	Slope	%	P value	Inches	%
	South Fork										
1	Selection cut, burn, interim	44	0.0-2.5	-0.28	-86	ns	0.303	69	0.0001	0.58	63
2	Commercial	44	0.0-2.5	-.005	16	ns	.423	96	.001	.85	92
3	Selection cut, burn, interim	37	0.0-0.5	.002	75	ns	-.118	-13	ns	0	0
4	Commercial	39	0.0-0.5	.012	382	ns	.186	20	.06	.11	22
	North Fork										
5	Moist site	25	0.0-2.5	-.005	-17	ns	.262	32	.0001	.52	31
6	Dry site	44	0.0-2.5	.032	119	ns	.121	15	.02	.27	16
7	Moist site	20	0.0-0.5	.002	37	ns	.400	33	.02	.20	33
8	Dry site	39	0.0-0.5	.022	548	ns	.310	26	.02	.18	29

[1] Increases in winter stormflow were calculated at 0.5 inch of control flow using the regressions for the 0-0.5 inch data range, and at 2.0 inches using the regression for the 0-2.5 inches data range.

However dramatic the percentage changes appear to be, they are modest in terms of actual flow volumes and peak rates. The greatest changes were produced by the wildfire on South Fork, where an increase of 564% was equivalent to a 0.045-inch runoff from a 2-inch storm, or about 2% of the rainfall. The 858% change in peak flow was equivalent to an increase of 34 csm. However, except for very localized impacts on the watershed and in the channel, the actual increases were too small to be of significance from a land management standpoint. Even the wildfire related increases were readily absorbed in the channel system within a mile or so downstream, although a larger burned area would have had a greater impact downstream.

Winter stormflow increases were readily detectable only for treatments that affected vegetation on one-third or more of the watershed. The increases are primarily attributed to lower growing-season evapotranspiration, which results in quicker soil recharge and more efficient moisture movement. Summer storms contributed little to streamflow other than rain falling directly onto the channel surfaces and streamside areas. Therefore, the potential for downstream flow rates to be materially affected by treatment is greater in winter than in summer. This is anticipated, since most of the water yield increases detected in the annual streamflow analyses, up to 110% on South Fork, must be accounted for in the wet season flows. However, we looked at less than one-third of the total streamflow in our analyses because snowmelt, which dominates the runoff process at Workman Creek, was not included. Water yield studies in Colorado have suggested that the effects of forest treatments on snow accumulation and on snowmelt account for a major part of the increased runoff (Troendle 1983).

There is evidence from studies in Oregon and California, for example, Ziemer (1981), that large stormflows are not greatly affected by forest treatments. We were unable to verify similar trends at Workman Creek because of the small number of large storms, although observation during a few large rain on snow events suggest little or no difference between treated and untreated responses from the three catchments. Therefore, we generally agree with the concept that upstream treatment effects tend to become negligible once the soil mantle is fully charged. At that point, the amount of precipitation or snowmelt entering the system determines streamflow volumes.

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The Influence of Pinyon-Juniper on Microtopography and Sediment Delivery of an Arizona Watershed

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Abstract--Hummocks formed by litter fall of pinyon-juniper trees resulted in soil formation. Overland flows were diverted and slope gradients decreased by about 57%. In turn, streampower decreased. It is proposed that this was responsible for the decreased sediment delivery. Where buffer strips exist below non-wooded areas, sediment delivery was practically nullified.

In the Southwest, woodlands cover an area of about 25 million hectares. Pinyon-juniper represents an important vegetation type on this land, and occupies more than seven times the area of chaparral in Arizona. The use of this large area is limited to cattle grazing, fuelwood cutting, and occasional recreation. More intense use of the resource, such as charcoal production, started in places but failed on economic grounds. Vegetation type conversions to grass were unsuccessful because of increased erosion and insufficient water yield increases (Gifford et al. 1970, Gifford 1975, Roundy 1976). Unauthorized tree cutting is problematic in woodlands near rural communities, largely because of insufficient manpower available to management.

With the exception of silvicultural and fire research, pinyon-juniper has received little scientific attention. Thus very little is known about the erosional processes operating in this vegetation type, and the interactions between vegetation and erosion processes.

Pinyon-juniper usually occurs in open stands with wide spacings between individual trees. Some stands form large clusters. The question therefore arises: can mosaic distributions of pinyon-juniper significantly influence overland flow and sediment transport? The primary objectives of our ongoing study are therefore to quantify overland flow and sediment delivery, and to determine their production is influenced by pinyon-juniper.

Study Area

Located at an average elevation of 2,300 m in the Arizona White Mountains, the study watershed represents the typical present-day condition of the pinyon-juniper zone in the Southwest: overgrazed by cattle during the turn of the century, followed by controlled grazing and fuelwood harvest. During our study, fuelwood cutting was not permitted on the watershed. The climate is semi-arid with 395 mm average annual precipitation, of which 66% falls in summer. Summer storms are of high intensity. From November to April, precipitation is mainly in the form of snow. The soils of the area are sandy clay loams, with basalts forming the geologic base.

Method

Thus far, only two years of data are available. Twelve microwatersheds, or hillslope segments, were selected to represent three different woodland cover types: (1) four wooded, (2) six non-wooded, and (3) two non-wooded with buffer strips on the downslope border. Wooded cover formed a mosaic pattern comprised of open areas and trees and tree clusters. In this type, erosion pavements averaged 40% of the area. The pavements were a matrix of different rock sizes covering the ground surface. Ground cover of the non-wooded or open areas consisted of erosion pavement in nearly all cases.

Pinyon-juniper buffer strips consisted of 5- to 8-m-wide strips of trees close to the topographic contour. Open areas upslope from the strips had bare ground and erosion pavement. The trees in the strips were spaced so closely that erosion pavements did not exist between them, and the ground was fully covered by needle fall. Of the total area, erosion pavement averaged at 60%.

These small microwatersheds were neither subwatersheds nor plots. Generally, subwatersheds are larger in size. In contrast to plots, gentle topographic swales represented the

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microwatersheds where available. When not available, the miniature watersheds were hillslope segments bounded by 20-cm-wide sheet metal strips sunk about 10 cm into the ground. These strips were also placed where the natural overland flow divides were not sufficiently pronounced to prevent breaching during strong runoff events.

At the downhill drainage boundary, 4-m-long prefabricated metal troughs were installed. These conveyed the water-sediment mixture into tanks, where overland flow volumes and sediment concentrations were measured after each storm. Where expected flow volumes were too large for the tanks, home-made splitters (consisting of a steel blade installed plumb into a 10-cm pipe) wasted 50% of the flow volume and conveyed the remainder to the tank.

At least one continuously recording flow gaging station was placed in each cover type drainage. Small supercritical flumes with waterstage recorder or bubble flow meter and pumping sediment samples were used. The bubble flow meter and sediment sampler were synchronized so that flow hydrographs delivered by the meter could be correlated with sediment yields.

Since microwatersheds occupied different aspects and elevations on the mountain slopes, a precipitation gage network was installed so that individual estimates for each drainage were obtained.

No unusual precipitation or flow events occurred during the study period. To determine whether precipitation during the study years was normal, 14 years of data from a station, 5 mi from the study site, were compared. A linear regression between the precipitation of the nearby-station and the study area showed a coefficient of determination (r^2) of 0.71. Based on this regression, our precipitation data were calculated back to 1972. The estimated mean precipitation (453 mm) did not differ significantly from the actual mean 423 mm) ($p = 0.5$), indicating that precipitation was normal during the study period.

Statistical analyses consisted of analysis of variance and Student's t-test.

Results and Discussion

Sediment deliveries from the three vegetation cover types varied greatly (table 1). Wooded areas produced an annual average of 165 kg ha^{-1} yr^{-1}, non-wooded 556 kg ha^{-1} yr^{-1}, and non-wooded with buffer strip 31 kg ha^{-1} yr^{-1}. However, when overland flows were compared between wooded and non-wooded conditions, no significant difference ($p = .05$) could be found. This contrasts with the sediment deliveries that were significantly different ($p < .01$). Student's t-test was applied.

The apparent contradiction between similar flows but dissimilar sediments was puzzling. Both types had erosion pavements. Earlier studies have shown that erosion pavements are high sediment producers on a watershed[2, 3] (Heede 1984).

At times, annual herbaceous vegetation invaded the erosion pavement, but never represented more than 2-3% of the cover. In contrast to the wooded area, erosion pavement formed a continuous ground surface cover on the non-wooded study sites. No apparent relationship was observed between slope gradient and sediment delivery. For instance, on wooded slopes, 175 kg ha^{-1} yr^{-1} were delivered from a 17% gradient and 172 kg ha^{-1} yr^{-1} from a 34% gradient (table 1). This implies that slope gradient was not the main influencing variable.

Inspection of the microtopography of the hillsides showed that each tree and tree cluster had formed a mound protruding up to 0.36 m above the surrounding ground surface. Average mound height was 0.20 m with a standard deviation of 0.08 m. The outline of this mound coincided with the dripline of the tree. Viewed from some distance, the mound formations transformed the hillsides into a landscape of miniature hummocks. Individual hummocks were formed by deposition of dead needles. Hummock height tended to increase with age of tree. In contrast with erosion pavements surrounding the hummocks, soil had developed beneath the litter and duff layers. Where trees had died or were removed, the hummocks began to shrink in size and finally disappeared. As this happened, the soils of the hummocks also disappeared, and erosion pavements replaced the hummocks underneath the tree "skeletons."

Overall, hummocks appeared to be effective barriers for overland flow, and only seldom was one overrun (indicated by rill formation). In nearly all cases, diversion of the overland flow was diverted around the hummock, as evidenced from the flow pattern after storm events. This diversion produced considerable lengthening of the flow lines compared with more or less straight downhill flows. If we consider the ideal case of a hummock with a true circular circumference, the increase in flow length necessary to reach the same elevation as existing at the tree (center of circle) is 57% (because the length of the flow line r, the radius of the hummock, is increased to $1/2\ r\ \Pi$, one fourth of the circle's perimeter). From this follows a decrease of the flow gradient by 57%. Of course, we are not dealing with a tilted tabletop and regular geometric form; this decrease could therefore be somewhat larger or smaller. But the point is that a substantial gradient decrease takes place which, in turn, leads to decrease of the velocity of flow.

Slope and velocity are two important variables for stream-power, an expression for sediment carrying capacity of the flow. Bagnold (1973, 1977) described stream power (ω) by the equation

[2]Heede, Burchard H. The influence of vegetation and its distribution on sediment delivery from selected Arizona forests and woodlands. In preparation for Proceedings of Nineteenth Annual Conference of the International Erosion Control Association. 1988.

[3]Heede, Burchard H. Overland flow and sediment delivery five years after timber harvest in a mixed conifer forest, Arizona, U.S.A. Journal of Hydrology (In press).

Table 1.--Average annual overland flow and average annual sediment delivery from the three different vegetation cover types. Standard deviations given in parenthesis.[1]

Microwatershed No.	Aver. slope gradient	Overland flow	Sediment delivery
	$m\ m^{-1}$	$mm\ yr^{-1}$	$kg\ ha^{-1}\ yr^{-1}$
Wooded			
3	0.17	3.8	174.83
5	.34	1.6	195.39
12	.34	3.6	172.42
13	.28	.7	117.87
Average	.28 (0.20)	2.4 (1.5)a	165.13 (28.71)a
Non-wooded			
4	.33	4.0	291.73
6	.35	3.1	828.46
7	.34	2.7	353.38
9	.41	4.5	623.85
10	.10	2.0	405.71
11	.12	7.8	835.69
Average	.28 (.12)	4.0 (2.0)a	556.47 (220.05)b
Non-wooded with bufferstrip			
1	.29	.9	46.94
15	.20	.7	15.45
Average	.25 (.06)	.8 (0.2)b	31.20 (22.88)c

[1]Within a column, significant differences between classes are indicated by different letters (flow, $p = .05$, sediment, $p < .01$).

$$\omega = \gamma\, dSv \qquad [1]$$

where q is the absolute density mass per volume, d is the mean flow depth, S is the energy slope, usually substituted by bed slope, and v the mean flow velocity. As can be seen from this equation, the computation of absolute changes in stream power induced by overland flow diversions would be theoretical, since mean flow depth, mean velocity, and their changes would have to be estimated, while γ could be taken as constant. Measurements of the variables under field conditions possibly would lead to closer estimates, but not to absolute values, due to the difficulties of measurements in shallow flows and rapidly changing depths and velocities. It can be reasonably assumed that slope gradient and velocity will substantially decrease, exceeding any possible increase in flow depth due to lack of channelization. In turn, this leads to wider flows, increased wetted perimeter and roughness of flow, and decreased velocities.

Figure 1.--Buffer strips consisted of a cluster of trees that had formed on continuous mound underneath their crowns. The overland flow and sediment collector trough is located at the bottom of the figure (looking upslope).

Thus, streampower would decrease with overland flow diversions induced by hummocks. Generally, diversions occur several times as water flows downslope, resulting in flow regimen changes from a turbulent to a more tranquil flow, and further decreased sediment carrying capacity.

It is proposed, but has not been tested, that the significant difference in sediment delivery between the pinyon-juniper mosaic pattern and the open area is caused by the hummock formations. The apparent contradiction that hummocks led to decreases in sediment delivery, but slope gradient-sediment delivery relationships did not exist on the microwatersheds, can be explained by the cumulative effect of several hummock diversions.

Unfortunately, only two sites of non-wooded areas with buffer strip had a complete data set (table 1). If we assume that average sediment production on the erosion pavement upslope from the buffer strips was similar to that from the non-wooded sites, only an average of about 6% of sediment left the buffer strip. In ponderosa pine (Heede 1984) and in chaparral (Heede, in preparation[2]), only 2% and 0.4%, respectively, left the buffer strips. The face value of the data is not as important, as what they reveal about processes.

The data indicate that pinyon-juniper buffer strips were more effective in reducing sediment delivery than the wooded sites, because the upslope microtopography forced the overland flow to enter the extended hummock of the strips' tree clusters. Therefore, due to increased infiltration, the litter-soil ground cover underneath the trees reduced the flow and with this the sediment load.

Conclusions

Sediment delivery from wooded areas was lower than from non-wooded sites, but overland flow was not. Pinyon and juniper trees changed the microtopography by forming mounds, or hummocks, whose edges corresponded to the tree's dripline. Litter, duff, and soil making up these hummocks protruded up to 0.36 m above the surrounding ground surface. I observed that the elevational difference forced overland flow to circumvent the trees. This caused extension of the flow lines and reduction of the slope gradient by about 57%. If the flow line extension is the predominant variable responsible for the decrease of sediment delivery, resulting decrease of sediment carrying capacity of the flow would explain the reduced sediment delivery from wooded sites.

Sediment delivery from pinyon-juniper buffer strips was practically nil. Similar results had been obtained by the author below buffer strips in ponderosa pine and chaparral.

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Environmental Limitations to Photosynthesis in Subalpine Plants of the Central Rocky Mountains, USA

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Abstract--In the subalpine forests of the central Rocky Mountains, the specific environmental factors which limit photosynthetic carbon gain of the conifer tree species during the summer growth period are not well understood. Suboptimal air and soil temperatures, soil and air dryness, and cloudcover have been identified as potentially important factors which interact to limit summer carbon gain. Recently, our studies using field gas exchange measurements of photosynthetic carbon assimilation in the dominant tree species indicate that prolonged, near-freezing air temperatures and cool soil temperatures (< 8°C) exert a strong inhibition during early summer. Soil drying appears to have potentially strong influences only at lower elevations while the stomatal response to air dryness is secondary during most of summer.

The summer growth period in the subalpine region of the central Rocky Mountains is characterized by extremely variable environmental conditions that are enhanced by the structure of the lodgepole pine and spruce-fir forests. The openness of these forests enable substantial sunlight penetration and, yet, wind speeds may be severely reduced (Smith 1985). These environmental characteristics result in a host of relatively unique stresses that are apparent in the ecophysiology of the endemic conifers. For example, air temperatures may approach freezing at night during any summer month and, yet, rise to 20°C during the day. Soil temperatures may not exceed 10°C at 10 cm depths within the forest where considerable shade and snow accumulation can result in prolonged snow cover. Yet, low ambient humidities (< 20% rh) and high vapor pressure deficits (> 5 kPa) appear common and the biophysics of high elevation generates an especially strong evaporative demand on plant tissues (Smith and Geller 1980). Table 1 and figure 1 summarize some of the hypothetical, temporal aspects of the above environmental parameters which are potential limitations to photosynthetic carbon gain during the summer growth period.

While understory saplings experience considerable portions of day in shade, even adult overstory trees also experience regular and substantial summer cloudcover due to daily advectional cloud formation particularly in the afternoon. A major portion of a typical summer day throughout the entire summer may be cloudy with substantial periods of reduced sunlight levels that are well below photosynthetic saturation (Knapp and Smith 1987, Young and Smith 1983). Virtually no information exists regarding the importance of cloudcover regimes to seasonal carbon gain in subalpine species.

Over the past several years we have attempted to identify and quantify the specific environmental limitations to carbon assimilation imposed at a particular time of summer by a single environmental factor. We realize that at any given time an interactive effect of many environmental variables is most likely occurring. However, by attempting to quantify individual influences, identification of the most important factors will be possible and will subsequently enable an evaluation of the specific structural/physiological capabilities in a species that might be most adaptive. Our ultimate goal is to be able to evaluate the importance of physiological adaptations to natural distributional and successional processes as well as to the reestablishment and regeneration problems important for successful subalpine forest management.

Our initial approach was to focus on leaf conductance (stomatal behavior) patterns in subalpine conifers as an overall indicator of the potential for carbon assimilation and growth. We have recently begun to utilize photosynthetic measurements which enables quantification of both stomatal (leaf conductance of CO_2) and non-stomatal (cellular, enzymatic processing of light and CO_2) limitations to photosyn-

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Table 1.--Hypothetical interaction between plant and environmental water parameters within the sprucefir zone during the growth season. Double asterisks indicate a primary limiting effect, either directly on stomatal opening (stomatal) or indirectly through limitations on water uptake from soil and/or movement to the leaves (recharge). Single asterisks denote important, but less significant effects. Based on the interactive model proposed by Smith et al. (1984).

	Late spring		Early summer		Midsummer		Late summer		Fall	
	stomatal	recharge	stomatal	recharge	stomatal	recharge	stomatal	recharge	stomatal	recharge
Air temperature	**	*		*					**	*
Soil temperature at root depths		*		**		*				*
Morning xylem pressure potential	*		*				*			
Afternoon xylem pressure potential					*		**			
Soil water potential at root depths								**	*	
Leaf-air water vapor deficit			*			*	*			

thetic carbon assimilation (Jones 1985). Although stomatal function is especially appropriate for water relations studies, photosynthetic limitations due to non- stomatal influences are often of equal if not greater importance (Farquhar and von Caemmerer 1982).

Methods and Materials

All measurement sites were located in the Medicine Bow Mountains of southeastern Wyoming. The dominant conifers include lodgepole pine (*Pinus contorta* Dougl. ex Loud. ssp. *latifolia* (Engelm.)), subalpine fir (*Abies lasiocarpa* Nutt.), and Engelmann spruce (*Picea engelmannii* Parry). Data presented in the following sections are based primarily of field gas exchange instrumentation utilizing cuvettes that enclose branch tips, including primary and/or secondary shoots. Smith

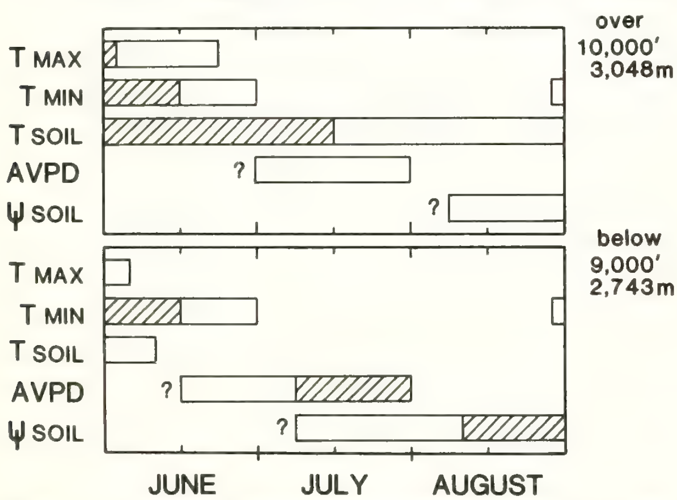

Figure 1.--A hierarchial model of environmental limitations to photosynthesis in Engelmann spruce. The hatched bars indicate a strong limitation (> 20%) and the open bars indicate a slight limitation (5 to 10%) to photosynthesis at high (≥ 10,000 feet, 3048 m) and low (≤ 9,000 feet 2743 m) elevations.

and Hollinger (1987) provide a recent and detailed review of this approach. Also, the references provided in the following sections include detailed descriptions of the specific methods and materials corresponding to an indicated data set.

Results and Discussion

Although numerous studies have dealt with the influence of specific environmental factors on photosynthetic performance, (see Jarvis 1980, Schulze and Hall 1982 for reviews) only a few have attempted a comprehensive evaluation of the relative importance of different environmental constraints at different times of the growth period to seasonal carbon gain. Many of these latter studies have focused on stomatal conductance patterns without photosynthetic measurements (Kaufmann 1982a,b; Smith et al. 1984, Smith 1985a). Stomatal behavior patterns appear to be strongly influenced by photosynthetic photon flux density (PPFD), plant water status (xylem pressure potential, XPP), the leaf-to-air vapor deficit (LAVD), and leaf temperature (fig. 2). In addition, nonstomatal limitations may also involve PPFD and water status, as well as other factors such as carbohydrate feedback inhibition and hormonal effects that have direct consequences on the cellular processing of light energy and the carboxylation process (Delucia 1986).

Air and Soil Temperature

It has been proposed that the temporal sequence of which specific environmental parameter is most limiting to photosynthesis may proceed as depicted in figure 3 (Smith 1985b). Initially in early summer, the continuing (although sporadic) occurrence of near-freezing nights causes a major reduction in stomatal opening and photosynthesis on subsequent days (Delucia 1987, Fahey 1979, Neilson et al. 1972, Pharis et al.

1970, Smith et al. 1984, Smith 1985a). Cold air drainage may extend low nighttime needle temperatures to lower elevations (Kaufmann 1984a). Figure 4 shows the fairly dramatic increase in leaf conductance and net photosynthesis for four subalpine conifers immediately following the onset of above-freezing nights in June. Prior to this disappearance of below-freezing nights, it appears that the capacity for net photosynthesis is approximately half of the maximum rates measured during summer (Delucia and Smith 1987) while leaf conductance may also be severely depressed to even lower values relative to maximum seasonal levels (Smith 1985b). Similar reductions in leaf conductance has been reported for six subalpine conifers after the onset of freezing nights in fall (Smith et al. 1984).

In contrast, low daytime air temperatures appear to have a minimal impact compared to nighttime minimums, at least for clear days. Considerable warming of conifer needles above air temperature under full-sun conditions results in temperatures that are within a relatively broad and high temperature range for maximum photosynthesis (Delucia and Smith 1987, Smith and Carter 1987). Optimal temperatures for photosynthesis, that were considerably higher than maximum daily air temperatures, were attributed to a relatively dense needle packing in conifers (Smith and Carter 1987). As a result, a relatively high percentage of the daytime may be spent within the optimal photosynthetic temperature range (table 2).

Soil temperatures may remain considerably below about 10^{o}C during much of the summer growth period within the subalpine forest (fig. 5). Moreover, seasonal increases in leaf conductance and net photosynthesis appeared correlated with increasing soil temperatures throughout June and July. Potted seedlings of Engelmann spruce had similar response patterns in leaf conductance and net photosynthesis as root temperatures were experimentally increased from near 0^{o}C to 20^{o}C (fig. 6, Delucia 1986). Successive days of exposure to chilling root temperatures caused a dramatic decrease in photosynthesis due primarily to non-stomatal limitations.

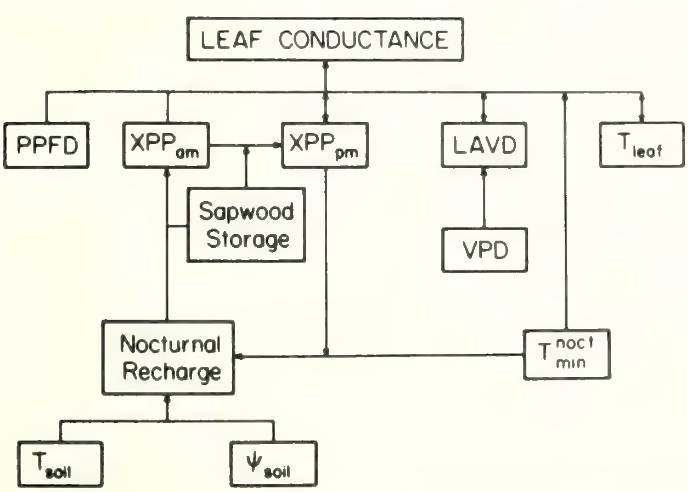

Figure 2.--Interactive relationships between environmental variables, plant water status, and leaf conductance to water vapor diffusion in conifers (Smith et al. 1984).

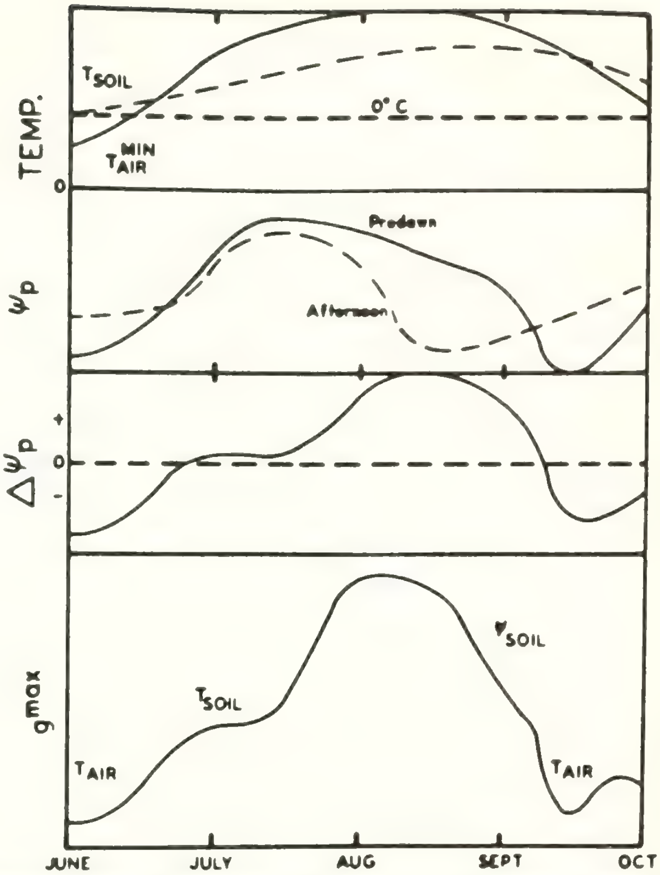

Figure 3.--Idealized relationships between air and soil temperatures, predawn and afternoon minimum, and maximum leaf conductance to water vapor during the day (Smith 1985b).

Because both cold air and soil temperatures may be simultaneously limiting photosynthesis during early summer, it is difficult to segregate independent effects of each. It is apparent that a more prolonged soil temperature inhibition occurs due to the relatively rapid disappearance of freezing nighttime temperatures in June (fig. 2-4). In fact, the laboratory data on the response in photosynthesis to root temperature (fig. 5-6) indicates that cold soil temperatures could be inhibitive for most of the summer at high elevation. Thus, there may be a relatively abrupt increase in photosynthetic capacity in early summer that is followed by a steadily declining inhibition due to cold soil temperatures at root depths.

Water Relations

The ultimate environmental factors influencing photosynthesis via water relations are soil water availability and LAVD. The plants capability for increased rates of water transport, water storage, and/or regulation of stomatal aperature to insure high water use efficiency will dictate the integrative influence of water relations on photosynthetic performance. There appears to be a rather complex seasonal interaction between cold temperature effects and, possibly, soil drying and LAVD (fig. 2). According to rather sporadic measurements in the subalpine forest over the past 8 years (1978-present) summer soil water potentials never fell below about

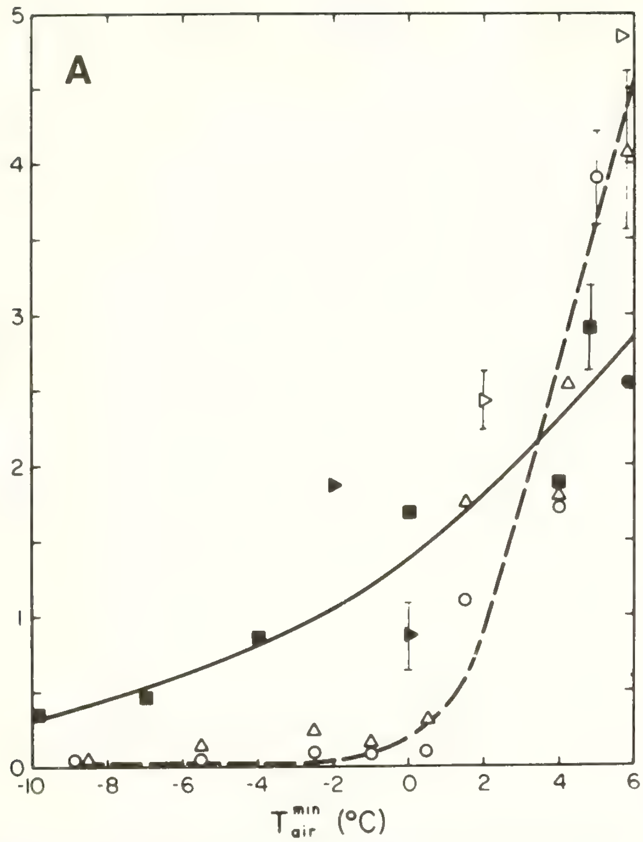

Figure 4A.--Maximum daily leaf conductance (g^{max}) versus the minimum air temperature on preceeding nights in spruce (△), fir (0), limber pine (▷) and average values for six common conifer species of the Central Rocky Mountains growing naturally at the same location. Solid symbols are for fall (Aug. 26-Sept. 30); open symbols are for early summer (June 5-July 15). Vertical bars represent greatest range of values for each data set (Smith 1985b).

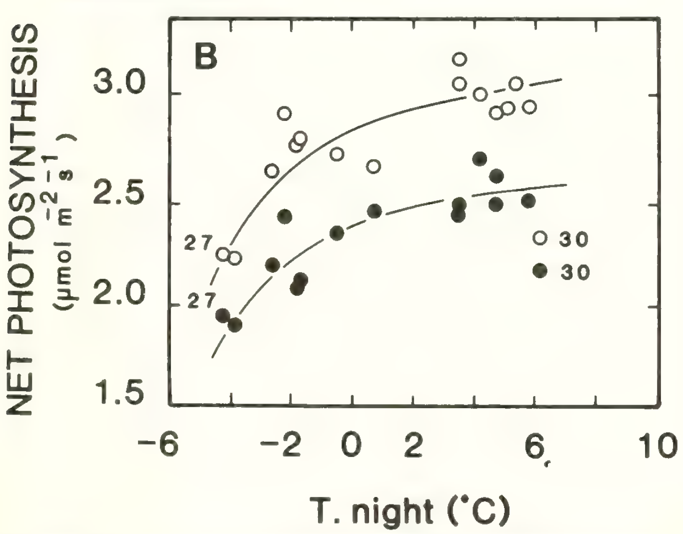

Figure 4B.--The photosynthetic response of Engelmann spruce trees in situ to minimum air temperature for the previous night. Measurements of trees in warm and cool soil are shown with open and closed circles, respectively. Each point is a mean of 5 independent measurements.

1.2 MPa at 10-15 cm depths for a total of over 300 measurement days at 14 different locations (Smith et al., unpublished). Regardless, when subfreezing air temperatures occur at night frozen stems could inhibit nocturnal sapwood water recharge from even wet soils and, thus, lead to lower water status at dawn. Recent data showing greater xylem pressure potentials later in the day compared to predawn values support this idea (Smith et al. 1984, Smith 1985a).

There are numerous reports indicating that stomatal behavior in coniferous trees may respond strongly to LAVD values above about 2 kPa. For subalpine conifers of the central Rocky Mountains LAVD may approach values exceeding 4 kPa due to needle temperatures that are frequently elevated well above air temperature (Smith and Carter 1987) while ambient humidities are usually low (< 20% relative humidity). At these high LAVD values maximum daily leaf conductance never exceeded 0.5 mm s^{-1} over 3 summers of sampling at four different sites (1982-1984). However, the actual frequency of occurrence of these highest LAVD values is quite low with the most frequent values near 1.5-2.0 kPa. The question arises as to how often partial stomatal closure occurs and, if so, how much influence is exerted on photosynthetic capacity. Partial stomatal closure can certainly have nearly proportional effects on transpirational water loss (disregarding needle temperature and LAVD adjustments), but considerably less effect on net photosynthesis if non-stomatal limitations are also present. Considerably more work is needed to clarify the photosynthetic influence of the stomatal response to LAVD under natural conditions.

Photosynthetically Active Radiation

Until recently the influence of variable sunlight has not been systematically evaluated as a limiting factor to photosynthetic carbon assimilation in subalpine conifers. Studies dealing with PPFD effects on subalpine conifer photosynthesis have almost exclusively dealt with successional questions involving understory saplings or seedlings. This is somewhat surprising since subalpine areas are always at relatively high elevation where strong orographic influences tend to create considerable moisture deposition and advective cloud formation. Recent evidence now suggests that cloud periods are common to subalpine areas and can be characterized according to duration, intensity, and frequency of occurrence (Knapp and Smith 1987, Young and Smith 1983).

Numerous, alternating exposures to direct sunlight and full shade may comprise over half of a typical day in the subalpine. Physiological adjustments to sun/shade transitions due to cloud pattern involve both stomata and non-stomatal responses (Knapp and Smith 1987). Considering only the length of time spent in full shade (4-6 hrs./day), the corresponding drop in net photosynthesis would deplete daily carbon gain by almost 50%. In general, full cloud shade intervals result in decreases in PPFD of from above 1800 mol m^{-2} s^{-1} to less than 400 mol m^{-2} s^{-1}, decreasing net photosynthesis to about one-half light-saturated values (light saturation points reported for

Table 2.--Importance of elevated needle temperatures to conifer shoot photosynthesis in P. engelmannii (S), A. lasiocarpa (F), and P. contorta (P) during the summers of 1982-1986. Plus and minus values are 95% confidence intervals (Smith and Carter 1987).

Period	Species	Number of shoots	Temperature range for maximum photosynthesis	Mean maximum daily air temperature (^{o}C)[b]	Maximum photosynthesis (% of day) Actual	T_a	Percent increase in daily CO_2 uptake[a]
June 9-23	S,F,P	2,2,2	13-22,15-24,13-25	13.8 . 2.3	64	32	26
June 1-16	S,F,P	3,3,2	14-24,14-26	15.6 . 1.9	59	30	29
July 16-24	F	2	14-26	16.7 . 1.6	56	29	33
July 1-14	S,F,P	2,2,1	15-27,14-25,13-24	17.4 . 1.8	65	32	35
July 16-28	S,F,P	2,2,2	16-26,15-26	16.9 . 1.6	49	26	20
Aug 17-24	S,F,P	4,4,4	15-26,14-24,16-23	14.6 . 1.9	53	31	29
Mean			14.1-25.1	15.8 . 1.2	58	30	29

[a]Each value is computed for the indicated number of fir sun shoots only.

[b]12-year means (1962-1974, Wyoming Solar Observatory, see text).

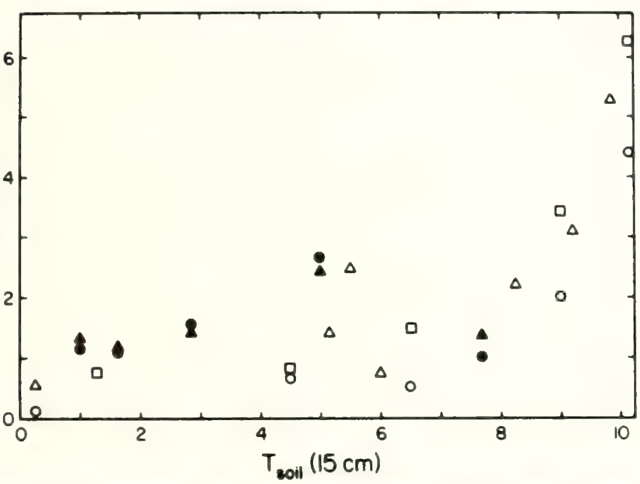

Figure 5A.--Maximum daily leaf conductance (g^{max}) and soil temperatures at 15 cm measured between 0600 and 0800 hr during the summers of 1982-84 (Smith 1985b).

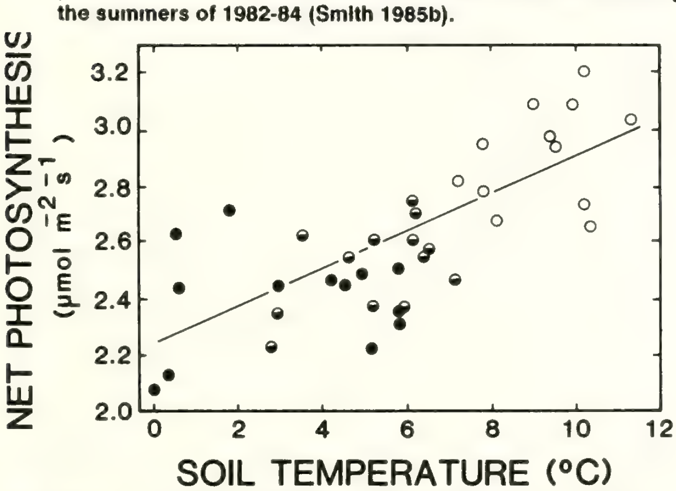

Figure 5B.--The photosynthetic response of Engelmann spruce trees in situ to soil temperature (15 cm) at the time of measurement. Each point is the mean of 5 independent measurements. Snow-free soil, partially covered, and completely snow-covered soil are indicated by open, half closed, and closed circles, respectively. Photosynthesis = 2.26 + 0.07 (soil temperature) (r^2 = 0.59, $p \leq .001$) (Delucia and Smith 1987).

mature trees of the central Rocky Mountains ranged from about 600-800 mol m^{-2} s^{-1} PPFD, Smith 1985b). Albeit, shade intervals generated by cloud cover could conceivably act to conserve transpirational water via stomatal closure and/or lower leaf temperatures and LAVD. Thus, a longer-term effect on water relations could be to enhance daily or seasonal water status, and, ultimately, seasonal carbon gain.

The shortterm changes in net photosynthesis and leaf conductance under variable sunlight regimes may have a major effect on daily and seasonal carbon gain and water loss. For example, a transition from full sun to cloud shade may cause a rapid decline in photosynthesis while the stomatal response is considerably slower. This would result in a continuation of transpirational water loss at very low photosynthetic carbon assimilation leading to low water use efficiency (mass CO_2/mass H_2O).

Recent investigations on alpine and subalpine plants has demonstrated that considerable differences in the degree of "coupling" between stomatal and non-stomatal responses during multiple sun/shade transitions can result in substantial differences in daily carbon gain and water loss (Knapp and Smith 1987a,b). Several herbaceous species respond to the numerous sun/shade periods (often > 80 per day) by rapidly changing photosynthetic rates as well as stomatal opening. Leaf conductance closely tracks photosynthetic rate resulting in high water use efficiency (fig. 7). In contrast, shrub and tree species including common central Rocky Mountain conifers show very little tracking between photosynthesis and stomatal conductance (fig. 8). In early summer, stomata in the conifers responded very slowly to shade intervals, resulting in relatively poor water use efficiency. However, recovery to previous full-sun photosynthesis after the return of full sunlight appears rapid in conifers. An adaptive response such as this would act to enhance carbon gain at the expense of water conservation. Also, it appears as though the capability in shrub and conifer tree species to maintain a constant and relatively high xylem water potential during full-sun exposure enables stomata to remain open during shade intervals and, thus, insure that

maximum photosynthetic rates are obtained rapidly following the return of full-sun. This maintenance of a high stomatal conductance during shade intervals would favor carbon gain over water conservation. Such a "strategy" might certainly be an advantage in cold-temperature habitats such as the subalpine zone where water may be less limiting than seasonal carbon gain. Whether or not shrub and conifer species show a better tracking between A and g later in summer when water stress is more likely remains a question.

Conclusions

At this time, it is difficult to make accurate quantitative, or even qualitative, predictions concerning the specific environmental parameters limiting photosynthetic capacity in subalpine conifers of the central Rocky Mountains. The complexity of the photosynthetic response (both stomatal and non-stomatal) to an equally complex set of environment variables combine to produce a challenging problem However, approximate estimations based on the data presented here predict that the following ranking: cloudcover, cold air and soil temperatures, LAVD, and soil moisture could provide a hypothetical order of importance for limitations to seasonal carbon gain. Early and late season appears dominated by cold air temperature limitations while the most important mid-season factors are predominantly soil temperature and LAVD. The specific influence of soil moisture is probably reflected in LAVD responses, increasing the importance of this stomatal response in late season. However, this conclusion is still primarily conjecture and further work is needed to add credibility to this idea as well as the other tentative conclusions expressed above and depicted in table 1 and figure 1.

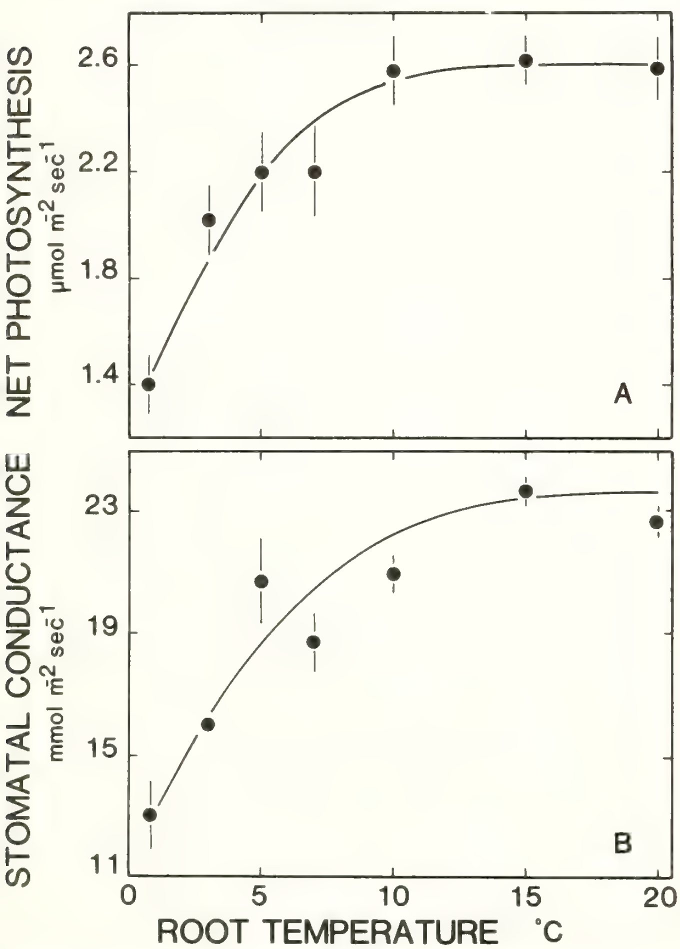

Figure 6.--The effect of different root temperatures and a constant shoot temperature (20 C) on net photosynthesis (A), and stomatal conductance (B) in potted Engelmann spruce seedlings. Curves were fitted by hand. Error bars are 1 SEM, N = 3 (DeLucia 1986).

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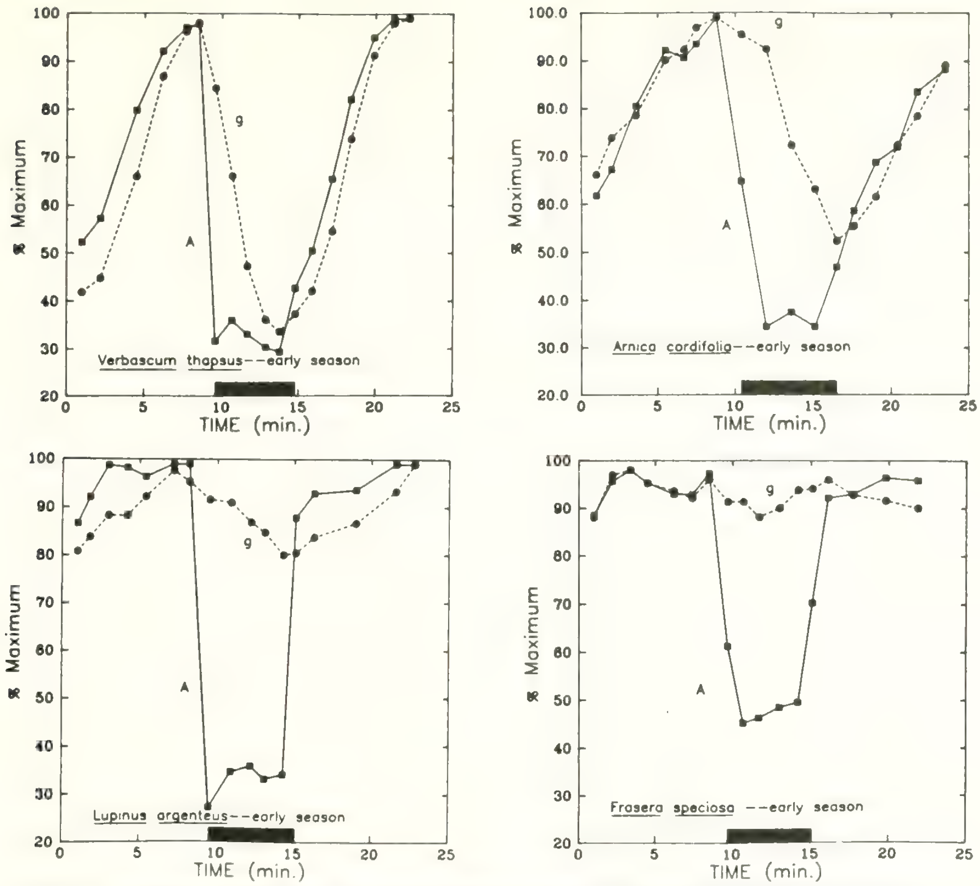

Figure 7.--Coupling of the A and g response in herbaceous species to alternating sun/shade intervals simulating cloudcover. Solid lines are A; dashed lines g.

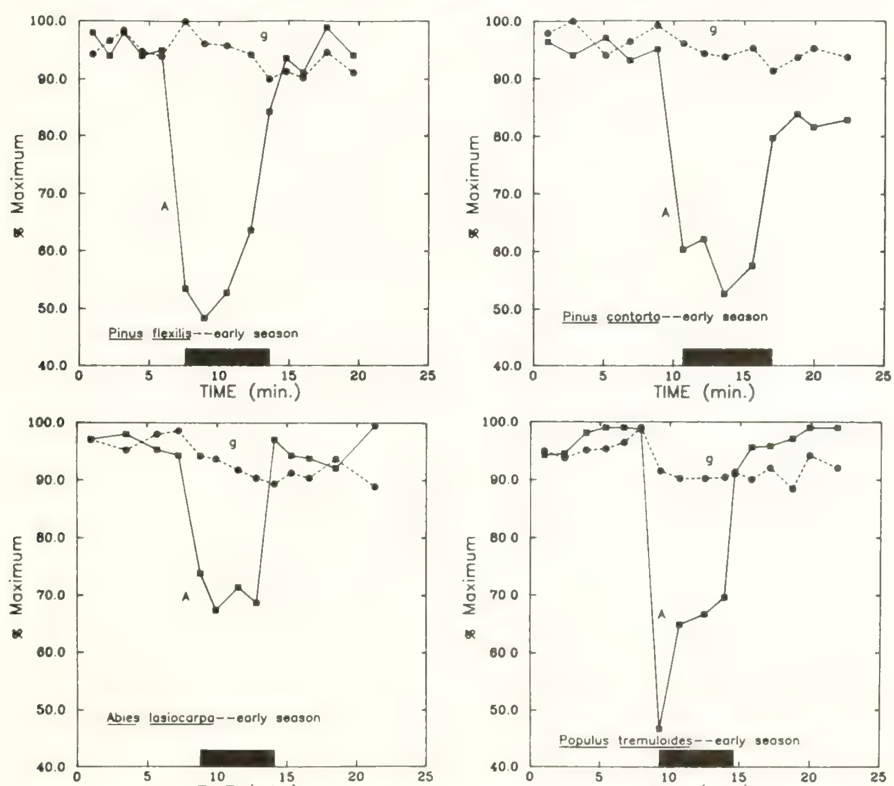

Figure 8.--Coupling of the A and g response in conifers to alternating sun/shade intervals simulating cloudcover. Solid lines are A; dashed lines g.

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Water Uptake of Subalpine Conifer Branches During Heating

W. B. Cohen, P. N. Omi, and M. R. Kaufmann[1]

Abstract--Transpiring pine, spruce, and fir branches were connected to potometers and some were treated with transverse cuts to induce a wide range of transport resistances. The branches then were heated in an oven at 225° C. During heating branches without transverse cuts transported water at significantly greater rates compared to their preheating transpiration rates, and branches which were treated with transverse cuts transported water at lesser rates than branches without transverse cuts.

A wildland fire in which the flames enter the vegetation canopy and consume its fuels is known as a crown fire. Crown fires account for only a small proportion of all forest fires, but because they are often so devastating, they are normally responsible for a disproportionately large share of the annual costs and damages associated with wildfires.

Conifer forests are a common setting for crown fire events. The crown of a live conifer tree consists of an abundance of needles and twigs (fuels) which are continually undergoing changes in their water relations (Chrosciewicz 1986, Fuglem and Murphy 1980, Jameson 1966, Philpot and Mutch 1971, Van Wagner 1967). In the annual water content profile of live conifer fuels there is commonly a period in spring when an apparent water deficiency (stress) is evident. Hough (1973), Van Wagner (1977), and Springer and Van Wagner (1984) have speculated that historical occurrences of conifer crown fire outbreaks in spring is linked to this period of water stress.

The only published results from experiments relating the water status of live conifer fuels to ignitability are by Quintilio (1977) and Van Wagner (1963). In both experiments, severed saplings were subjected to flames in a laboratory and a high correlation was found between foliage water content (expressed as percent dry weight and often referred to as moisture content) and the amount of fuel consumed. For dead fuels, water content may be a good measure of ignitability, but for live fuels both the mass of water and the mass of dry matter are variable (Gary 1971, Pharis 1967). Thus, a measure of live fuel water relations encompassing more than percent water content is probably desirable for assessing ignitability of live fuels.

Water enters and leaves living foliage in response to environmental and plant conditions (Kramer 1983). Rothermel and Susott (pers. comm., 1986)[2] hypothesized that live conifer fuels, when heated, may be capable of drawing upon water stored elsewhere in the tree and thereby forestall ignition. If live fuels have such a capability, a water relations index which is not only independent of dry matter variations, but which also incorporates a measure of water transport, may be a better indicator than water content of a live crown's susceptibility to ignition.

Using standard transport law, studies of water transport into tree foliage and of evaporation of water from the foliage surface have indicated that flow in both cases is regulated by a gradient or driving force and by resistance to flow (Fiscus et al 1983). For water supply to the foliage, the gradient typically is taken to be the difference in water potential between the point of supply and the foliage, and the resistances are those associated with liquid phase flow of water through xylem tissue. For evaporation from the leaf surface, the gradient is a vapor pressure deficit or a vapor concentration difference from leaf to air, and the resistances are those associated with vapor flow from the water surface in the tissue to bulk air outside the foliage.

In the field environment, the rate of water loss from foliage by transpiration is nearly equal to the rate of water transport into the foliage by the xylem. Small differences in these rates during the course of a day contribute to changes in foliage water content and to the development of midday water stress. We suspect that during a fire, foliage tissue rapidly becomes exposed to abnormal conditions in which the vapor gradient increases enormously because of leaf heating. In addition, high temperatures may sharply reduce the resistance of the foliage

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surface to water vapor loss. Under these conditions, evaporation from the foliage surface would increase dramatically. If the rate of water transport into the foliage remains the same as it was before heating, the tissue will dry rapidly, and if the temperature becomes high enough, the tissue will ignite.

Based upon this interpretation, the capacity of tissue to protect itself from ignition depends upon the ability of the transport system to supply water to the foliage. In this study, the role of water transport into tissue exposed to elevated temperatures is related to the initial rate of transport into the tissue and the initial foliage water potential. In addition, visual characteristics of the foliage are related to the transport rate during heating. The results from this study could provide guidelines for the development of an index relating foliage water relations within a conifer canopy to its susceptibility to ignition.

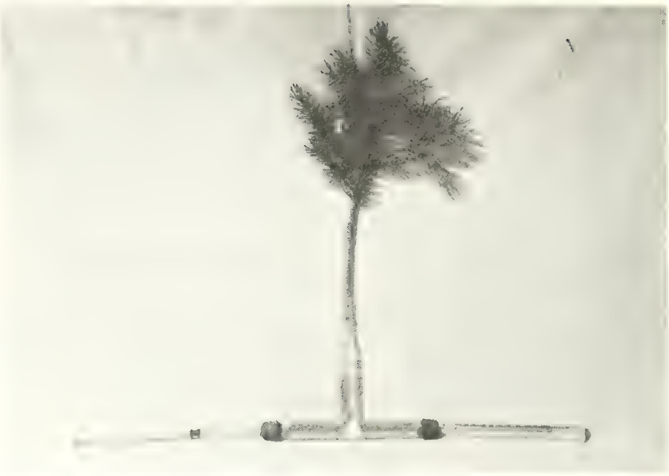

Figure 2.--An assembled potometer. Branch water uptake is measured in the barrel of the uptake measurement syringe. As needed, water transported by the branch is replenished with water from the recharge syringe.

Materials and Methods

During the period from February to June, 1987, freshly cut boughs from three conifer species, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), were brought to a laboratory weekly and refrigerated in plastic bags. As needed, branches were cut from the boughs and placed in specially designed potometers (figs. 1 and 2). The potometers supplied water to the branches continually and permitted branch transpiration rates to be monitored.

Branches were chosen by species in groups of four. They were selected according to size and health criteria, with the intent of selecting branches which were similar in form and vigor; branch selection was somewhat limited, however, which restricted application of the size criterion. The approximate ranges of length and diameter inside the bark of the branches were between 160 and 240 mm and between 2 and 4 mm, respectively. After attachment to the potometers, branches were allowed to stabilize for one day. To obtain a variety of water stress levels in the branches, on the second day, some branches were given two opposing transverse cuts (after Mackay and Weatherley 1973) to a depth of approximately 70% of their diameters. The separation of the cuts varied between 4 and 7 mm. The intent of the cuts was to inhibit flow and thus cause a decrease in water potential (an increase in stress). The other branches were left untreated. The laboratory environment included diffuse lighting, room temperature of approximately 23° C, and relative humidity which varied between 30% and 45%.

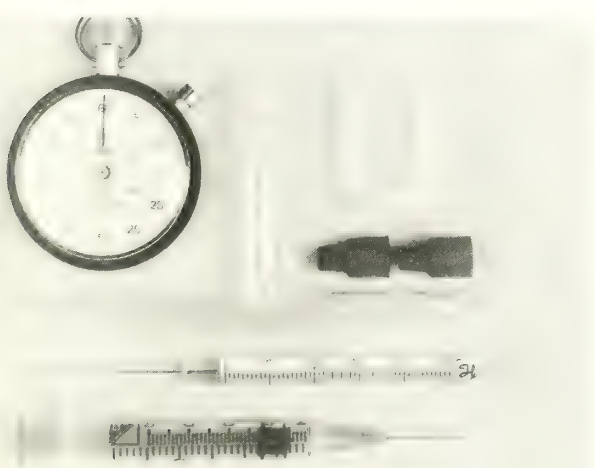

Figure 1.--Potometer used to monitor branch water uptake before and during heating. It includes: (top, left to right) a stopwatch, a glass tee, (clockwise) a short piece of flexible tubing, an automatic pipet tip, two rubber serum stoppers; (middle) an uptake measurement syringe with microliter resolution; and (bottom) a recharge syringe.

On the third day, branch transpiration rates were determined for a 6- to 10-minute interval. Water potentials were measured using a pressure chamber technique; for spruce and fir, branch tips were used (removing less than 10% of the leaf area) and for pine, needle fascicles were selected. Immediately after recording water potentials and transpiration rates, the branches were placed into the exhaust port of a convection oven which was set at a temperature of 225° C, with the potometers supported outside of the oven. Water uptake by the branches during heating was monitored every minute for twenty minutes. A total of 14 pine, 19 spruce, and 24 fir branches were heated. Visual observations during heating were made on 8 branches of each species. Foliage color and surface appearance were noted every minute.

Results

When branches were set up in potometers and given time to equilibrate, their transport rates rarely varied more than 15% per hour. When branches without transverse cuts were

placed in the oven, their water uptake increased substantially. Figure 3 shows the average rate of water uptake for the branches without transverse cuts, during 20 minutes of heating, normalized to the maximum rate during that time. Normalization minimized the effect of variability in leaf area and water potential from branch to branch. Initial transpiration rates prior to heating are shown at minute 0. Prior to heating, pine transported water at only 2% of the maximum uptake rate attained, which occurred around minute 6. Spruce and fir had prior uptake rates of 8 and 19% of maximum, respectively. While actual rates varied widely among species and with branch size, the pattern for normalized rates was similar for all three species when their capacity for flow was not initially inhibited by transverse cuts.

Foliage color during heating changed consistently among species in relation to position on the normalized water uptake curves (figure 3). All branches were green when first placed in the oven and by minute 1 were glistening. Glistening was associated with a decrease in water uptake. After minute 1, the foliage began to turn yellow and lose its glistening appearance. At this time, the rate of water uptake began to increase sharply. As the foliage began turning brown, water uptake quickly leveled off near the peak rate. After brown needles dried and became brittle, water uptake still occurred at rapid rates, declining only to 50% of the maximum in 9 minutes for pine and 13 - 14 minutes for spruce and fir.

Branches which had been treated with transverse cuts increased their rates of uptake during heating compared to their preheating transport rates, but had much lower rates relative to branches without transverse cuts. Figure 4 shows the uptake rates for the cut versus uncut branches for each species. A t test on the peak uptake rates for branches treated with transverse cuts against those without cuts revealed that uptake differences were significant at the .01 level for all species. The lower uptake rates by the cut branches are probably associated with increased resistances to flow from

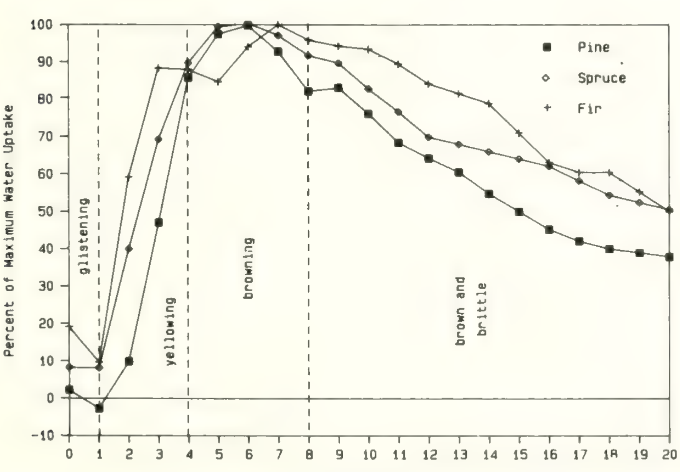

Figure 3.--Rate of water uptake during heating normalized over the maximum rate attained. Average rates for uncut branches, and foliage color changes associated with regions on the uptake curves are shown.

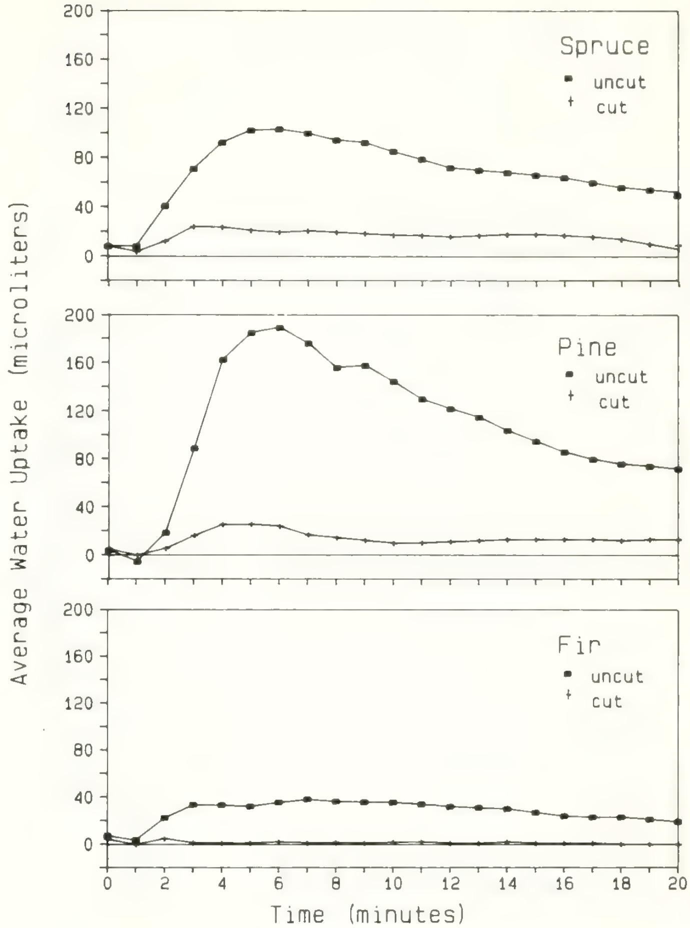

Figure 4.--Average water uptake rates for cut and uncut branches.

the cuts. The progression of color change during heating was generally more rapid for cut than for uncut branches.

In an attempt to determine if water loss from the branch's woody surface also influences water uptake during heating, a few branches of each species were heated just after removing all foliage. Impetus for this came from the fact that uptake continued even after all of the needles on the heated branches became brown and brittle. During heating, all defoliated branches transported water at higher rates than prior to heating, although rates were highly variable. Thus, it appears that the branch surface also may influence the amount of water transported during heating.

Discussion

Pine, spruce, and fir branches increased their water transport rates when heated. On a normalized basis, all 3 species underwent similar rates of change during the full 20 minutes of heating. The capability to increase water transport rates during heating supports the hypothesis that live conifer fuels may be able to draw water from the tree bole during heating and thereby forestall ignition.

On a normalized basis, foliage color changes were associated with changes in rates of water uptake for all three species. Because the progression of color change was more rapid on branches with transverse cuts, it appears that restrictions of water supply during heating also may cause more rapid damage to canopy foliage. Additionally, since the transverse cuts caused reductions in both peak and total water flow, water uptake during heating may be closely related to resistances to flow within the xylem tissue.

Initial foliage water potential prior to heating was not correlated well with water uptake during heating. Part of the reason for this is due to variations in branch size; ie, larger branches generally transport more water than smaller branches, all else being equal. Laboratory conditions also may have contributed to the poor water potential effect. Lighting intensity in the laboratory was low relative to the natural foliage environment. Because of this, foliage stomata probably remained partially closed, inhibiting transpiration, and thereby permitting the maintenance of a relatively high water potential. Although the water potential of branches treated with transverse cuts used in this study was not always lower, the cuts apparently increased transport resistance enough to sharply reduce water uptake during heating. In observations on branches moved temporarily into full sunlight, water potential generally decreased and transport increased. In future experiments, branches will be kept outdoors in more natural lighting conditions for at least an hour prior to heating, and water uptake will be expressed on a unit leaf area or xylem surface area basis. These improvements in technique should help to improve the possibility of discovering if initial water potential is a good indicator of water uptake during heating and/or ignition.

The study reported here will be continued using a specially designed calorimeter which will ignite live branches while measuring the energy required for ignition. The calorimeter will be used both on detached branches connected to potometers and on in situ branches. Experiments on the branches in potometers should permit the development of a relationship between water transported during ignition and the energy required for ignition. Water transported by in situ branches can then be inferred from the measured ignition energy.

A foliage water relations index which incorporates a measure of water transport may be useful in assessing a canopy's susceptibility to ignition. Field studies, using in situ branches, are needed to validate this assertion.

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The Diversity in Streamflow Response from Upland Basins in Arizona

Malchus B. Baker, Jr.[1]

Abstract--Although water yield from a basin is a function of a number of factors, soil depth is considered foremost in explaining hydrograph differences from study areas in Arizona. The most attenuated hydrograph found was in the chaparral vegetation type, which has the greatest soil depth, while the most responsive or peaked hydrographs were found in the pinyon juniper and ponderosa pine types, which have soil depths of 3 feet or less.

In Arizona, most of the 97 million acre feet of precipitation that reaches the soil is returned to the atmosphere and about 3% runs off as streamflow (Hibbert 1979). Nearly all of the water yield in Arizona is derived from 33% of the land area. Water yields range from 0.4 to 5 inches, with the ponderosa pine type contributing 59%, pinyon juniper 27%, chaparral 10%, and mixed conifer 4% of the streamflow.

Water yield is a function of geology, soil, elevation, orientation, vegetation, and climate. All of these factors modify to various degrees the disposition of energy and precipitation falling on an area and, therefore, the quantity of runoff or hydrologic response. The keys to the type of hydrologic response are (1) how far water must travel to influence channel flow, and (2) the mechanism by which it is delivered. Basins in Arizona have a large diversity of controlling factors, and consequently produce a significant amount of variation in streamflow response.

Objectives and Study Area

The objectives of this study were to select hydrographs from basins that demonstrate the diversity in streamflow response found in Arizona, and to identify the major factors responsible for the diversity. These basins include 3 Bar D in the chaparral vegetation type; three basins on the Beaver Creek drainage in the pinyon juniper woodland and ponderosa pine types; and Castle Creek, Thomas Creek, and Workman Creek in the mixed conifer type. Characteristics of these watersheds are presented in table 1. Additional information about these watersheds can be found in Baker 1986, 1984; Hibbert et al. 1974; and Rich and Thompson 1974.

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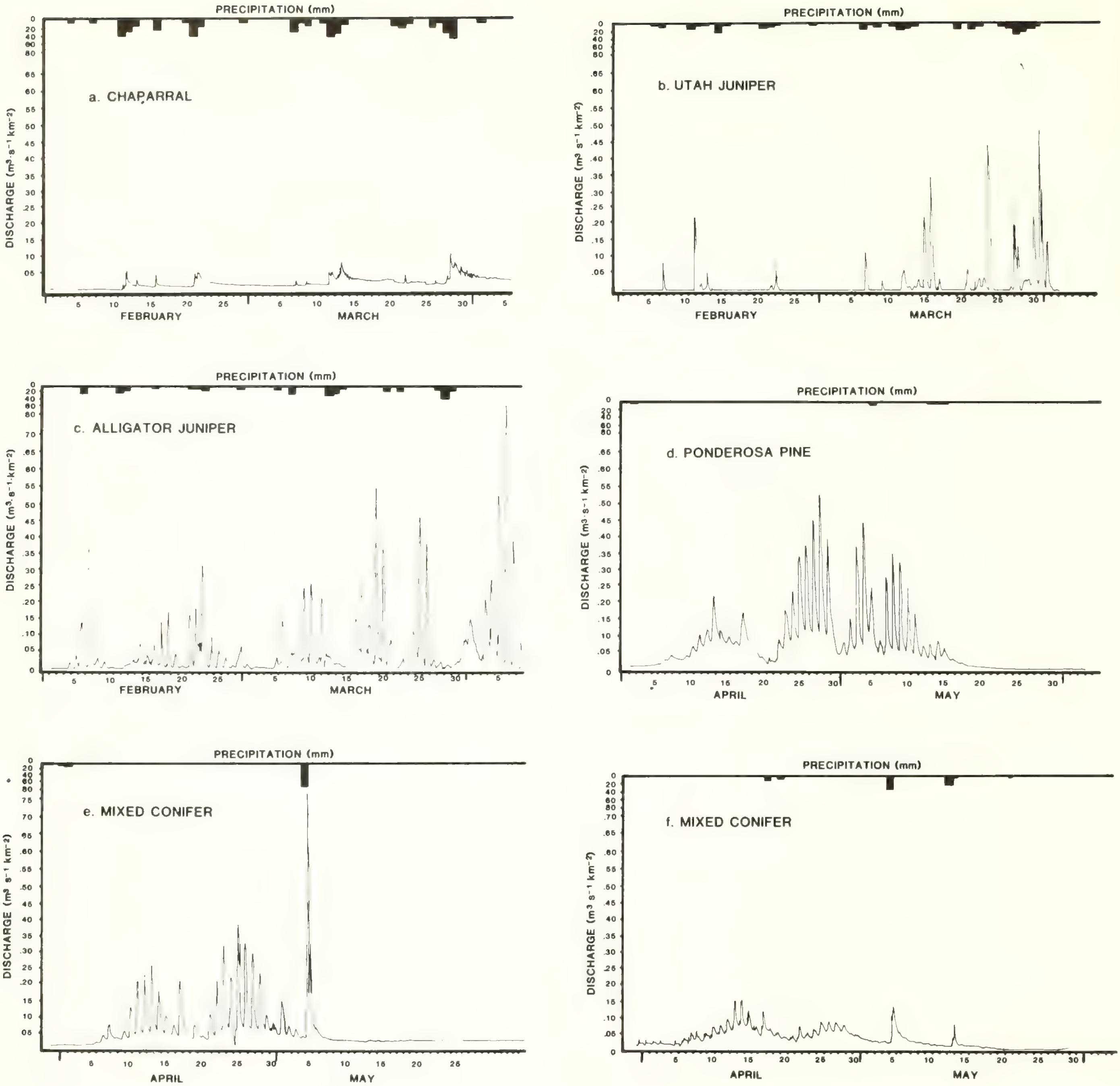
Streamflow Response

The shape of the hydrograph is an indication of the responsiveness of a basin, and is determined by the delivery rate of water and length of the flow path to the source area. The following spring streamflow hydrographs were produced during the unusually wet water year of 1973. Because of the large range in streamflow response derived from these basins, a wet water year was selected to avoid the potential problems caused by local soil moisture deficits that affect watershed response to precipitation and to snowmelt, and to insure that an adequate amount of streamflow was available for visual comparison of the hydrographs.

Streamflow in figure 1a is from the 3 Bar D chaparral watershed. Parent material is coarse granite. Soil in the basin includes all porous material in which weathering and roots are active, and reaches depths up to 30 feet (Hibbert et al. 1974). Streamflow normally occurs about one third of the time. October precipitation, which normally averages 2.7 inches totaled 14.6 inches in 1972. This unusually wet month resulted in the initiation of continuous flow from the normally ephemeral stream channel that continued throughout the remainder of the water year and on until June of 1974. Spring snowmelt began on February 11 (fig. 1a) at a baseflow level of 0.5 $ft^3 s^{-1} mi^{-2}$ gradually rising to a baseflow rate of 3 $ft^3 s^{-1} mi^{-2}$ on April 5, which then gradually receded back to 0.5 $ft^3 s^{-1} mi^{-2}$ on May 19. Peak discharges during this period were associated with rain on snow events; the first, on February 12, reached 5 $ft^3 s^{-1} mi^{-2}$. Discharge reached a maximum of 9 $ft^3 s^{-1} mi^{-2}$ on March 29. After each precipitation event, the general recession flow level was increased. Normal runoff to precipitation ratio on this basin is 0.13 while the same ratio for water year 1973 was 0.22 (table 1). Of the 11.4 inches of streamflow for the year, 6.4 inches or 56% was produced during the period of February through April.



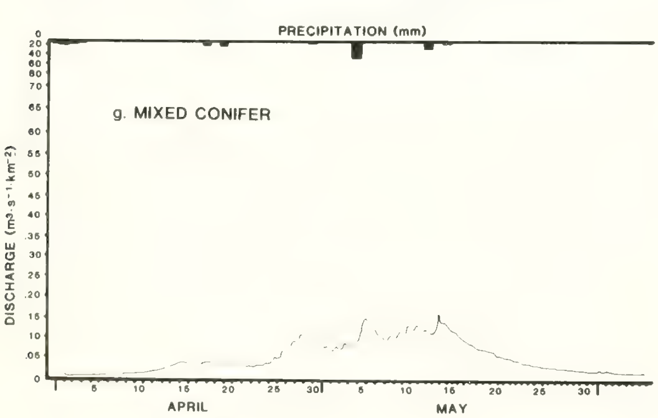


Figure 1.--Selected hydrographs demonstrating diversity in streamflow response (metric scale can be converted to $ft^3\ s^{-1}\ mi^{-2}$ by dividing by 0.0109.

Figures 1b, c, and d are streamflow hydrographs produced in three different vegetation types on the Beaver Creek drainage. Soils on Beaver Creek are developed from volcanic materials, primarily basalt, and depth is generally less than 3 feet. The soil typically has an A horizon that is 0.4 to 6 inches deep. Snow melts in the Utah juniper (fig.1b) during the same time period as in the chaparral type on 3 Bar D (February through April). Streamflow from this basin is much more responsive than from the chaparral basin. Daily discharge peaks are often over 10 $ft^3\ s^{-1}\ mi^{-2}$ and usually return to zero within hours, indicating much faster travel time and shorter flow paths. Saturated overland flow has been observed regularly during spring snowmelt on the Beaver Creek drainage. In water year 1973, measured runoff was 19% of the measured annual precipitation, with 61% of the streamflow occurring during the spring snowmelt period.

At a higher elevation, streamflow fluctuation in the alligator juniper type (Watershed 4) is also very high (fig. 1c). The daily peaks from snowmelt are more numerous and greater than peaks on the Utah juniper or chaparral basins (figs. 1b and a, respectively) reflecting the greater amount of snowpack at the higher elevation and smaller amount of overstory basal area on the alligator juniper basin. The highest peaks during this snowmelt period resulted entirely from snowmelt, reaching 51 $ft^3\ s^{-1}\ mi^{-2}$ on March 19 and 73 $ft^3\ s^{-1}\ mi^{-2}$ on April 6. Although streamflow did not go to zero until April 14, daily lows often approached 1 or 2 $ft^3\ s^{-1}\ mi^{-2}$. Periods of precipitation caused significant declines in flow by reducing incoming energy needed to melt snow.

The snowmelt hydrograph from the basin in the ponderosa pine type (Watershed 8) is almost free of any precipitation events, and was initiated about two months later than on the preceding basins (fig. 1d). Even for this wet year (46.0 inches of precipitation compared to the normal of 26.8 inches) spring snowmelt lasted only 6 weeks. Daily peaks would increase during a warming period, along with a similar increase in the slower subsurface flow component. Streamflow ended on May 29, indicating the reduced water storage capacity of this basin. Although daily peaks were generally greater than on the chaparral basin (fig. 1a), they were usually lower than from the less densely covered alligator juniper basin (fig. 1c). About 32% of the runoff produced during water year 1973 came during the April through May melt period.

The streamflow hydrograph from the mixed conifer type on the South Fork of Workman Creek (fig. 1e) reflects the higher water storage capacity of the basin (perennial streamflow) and overall lower responsiveness (generally lower daily peaks) (fig. 1d). Surface soils are loam to clay loam in texture; subsoil varies in texture from clay loam to clay (Rich and Thompson 1974). Soil depth varies from 2 inches to more than 15 feet. Snowmelt initiation is identical to that on the ponderosa pine basin at Beaver Creek (fig. 1d) but the daily peaks and delayed flow rates are generally not as high. A selection harvest on South Fork removed 46% of the merchantable timber; a second treatment converted the entire South Fork basin to ponderosa pine with 40 $ft^2\ ac^{-1}$ of basal area. This heavy reduction in overstory basal area has allowed more energy to reach the snowpack, resulting in the higher daily peaks from April 5 to 20 than observed on the ponderosa pine basin (fig. 1d). However, daily peaks during the latter part of April were smaller and snowmelt was essentially finished by May 5 on Workman Creek (fig. 1e) while continuing until after May 15 on the pine basin (fig. 1d). Maximum daily discharge peak (derived entirely from snowmelt) reached 35 $ft^3\ s^{-1}\ mi^{-2}$. Snowmelt lasted only 1 month, ending with a major rainfall derived peak of 72 $ft^3\ s^{-1}\ mi^{-2}$ produced by a storm event of 2.7 inches.

Streamflow patterns from the mixed conifer on East Fork of Castle Creek were similar to that on Workman Creek (fig. 1e) but more attenuated (fig. 1f). The Castle Creek area, at a

Table 1.--Physical characteristics of study watersheds.

Characteristics	3 Bar D	Beaver Creek Watershed 2	Beaver Creek Watershed 4	Beaver Creek Watershed 8	Workman Creek South Fork	Castle Creek East Fork	Thomas Creek South Fork
Vegetation type	Chaparral	Utah juniper	Alligator juniper	Ponderosa pine	Mixed conifer	Mixed conifer	Mixed conifer
Size (ac)	82	126	257	1804	319	1164	563
Mid area elevation (ft)	4200	5200	6250	7300	7150	8200	8700
Soil depth (ft)	30	3	3	3	13	<6	<6
Basal area (ft2 ac-1)	751	60	22	130	40	120	180
Annual precipitation (in)	29.5	18.1	20.1	26.8	31.9	25.6	29.1
Annual runoff (in)	3.9	1.2	4.3	6.9	3.5	3.5	3.2
AR/AP	0.13	0.07	0.21	0.26	0.11	0.14	0.11
1973 Precipitation (in)	53.0	26.8	34.4	46.0	62.4	37.0	42.9
1973 Runoff (in)	11.4	5.1	21.1	23.1	22.0	13.8	14.3
R/P	0.22	0.19	0.61	0.50	0.35	0.37	0.33

[1]Percent crown cover.

mean elevation of 8,200 feet, is predominantly covered by ponderosa pine, but is immediately adjacent to the extensive mixed conifer stands in the White Mountains of eastern Arizona. Because of its climatologic and hydrologic similarity to mixed conifer and dissimilarity to much of the ponderosa pine in Arizona, it is considered mixed conifer in this study (Rich and Thompson 1974). Soils are developed from basalt and depths are generally less than 6 feet with a heavy clay layer at 2 feet.

Peak flow and delayed flow increased daily during the warming period that began on April 6 (fig. 1f). Although the daily flow spikes are obvious, they are much less responsive than those on Workman Creek, indicating a higher relative resistance resulting from an integration of a slower water delivery rate and a longer flow path. Daily peaks were usually between 3 and 5 $ft^3\ s^{-1}\ mi^{-2}$ with the highest snowmelt peaks of 14 and 15 $ft^3\ s^{-1}\ mi^{-2}$ on April 13 and 14, respectively. Most snow was lost by the end of April. The streamflow events on May 5 and 14 are dominated by rainfall.

Streamflow from the mixed conifer type on the South Fork of Thomas Creek is often perennial, but occasionally ceases for a 1 or 2 month period. The basalt derived soils are generally less than 6 feet in depth. Streamflow in water year 1973 (fig. 1g) began to rise gradually on April 11, leveling off from April 15 through April 25, and then started to rise again. Daily fluctuation generally consists of a small increase, and then a leveling off until the next daily increase. Streamflow produced by rain on snow is obvious, such as on May 5 and May 13. The storm event on May 13 apparently depleted the snowpack because, after May 14, the hydrograph consisted of a gradual recessional flow which lasted through the end of the month. Although the annual precipitation of 42.9 inches (about 1.5 times normal) produced 14.3 inches of streamflow (4.6 times normal), maximum daily peak discharge only reached 12 $ft^3\ s^{-1}\ mi^{-2}$, excluding any influence of rain events which caused discharge to reach 15 $ft^3\ s^{-1}\ mi^{-2}$.4

Discussion

Although this is a limited set of hydrographs from one wet year (1973), some observations can be made, and one can get a feel for how much the various factors affect streamflow response, and how much these factors can interact in Arizona.

Runoff efficiency rates (ratio of runoff to precipitation) nearly doubled or tripled on all study basins in 1973, showing the influence precipitation can have on streamflow (table 1). The chaparral basin is at the lowest elevation, but receives the second highest average annual precipitation (29.5 inches). This basin had the most attenuated or least responsive hydrograph (fig. 1a), even though it received the second highest amount of precipitation (53.0 inches) in 1973. It also has the deepest soil (30 feet). Similar chaparral basins have been shown capable of producing perennial flow once the chaparral overstory is converted to grass, suggesting the influence of soil depth on the storage of precipitation and its eventual release (Hibbert et al. 1974).

The most responsive or peaked hydrographs occurred on the Beaver Creek drainage area with a mean soil depth of about 3 feet. The Utah juniper basin receives the lowest mean annual precipitation amount (18.1 inches). However, the influence of the soil depth and the relatively impermeable B horizon seems apparent in the highly responsive daily streamflow peaks (fig. 1b). Daily peak discharge rates, even from snowmelt, are relatively large and recede rapidly (in hours), which suggests a relatively small soil water storage capacity and short flow paths (overland flow and shallow subsurface flow).

Streamflow from the alligator juniper basin was similar to the Utah juniper basin, but the higher elevation, higher annual precipitation, and lower overstory basal area produced more numerous and higher daily peaks (fig. 1c).

The ponderosa pine basin on Beaver Creek has similar soil characteristics and similar responsive daily peaks (fig. 1d). However, its higher elevation apparently resulted in a delay of the snowmelt of about 2 months (from February to April). This basin has the highest long term runoff efficiency of the 7 study basins (0.26) and the second highest for the 1973 water year (0.50). Daily peaks were usually lower than on the alligator juniper basin, probably due to the influence of the less dense overstory basal area on snowmelt rates. Flow on the three Beaver Creek watersheds generally terminates within a few days of the disappearance of the snowpack, while streamflow often lasts longer on the other study sites. Even watersheds in the chaparral type, generally considered a dry vegetation type, can produce perennial flow after conversion of shrubs to more shallow rooting species, such as grass (Hibbert et al. 1974). The streamflow hydrographs from Beaver Creek also exhibit the greatest range in daily peaks and the largest range in mean annual streamflow (1.2 inches with 18.1 inches of mean annual precipitation to 6.9 inches with 26.8 inches of precipitation) (table 1).

Annual precipitation at the mixed conifer basin on Workman Creek is highest of the 7 study basins (31.9 inches), and streamflow is normally perennial. Hydrograph responsiveness is similar to that on the ponderosa pine basin, but daily peaks are higher in the beginning of the melt period and lower towards the end suggesting the influence of the heavy reduction in overstory basal area on snowmelt rates (fig. 1e).

Streamflow in the mixed conifer on Castle Creek is similar to that on Workman Creek, but is less responsive or more attenuated, probably as the result of the influence of the higher elevation (8,200 feet) on snowmelt rates (fig. 1f). Daily snowmelt peaks are still recognizable on Castle Creek but greatly reduced. Annual precipitation and overstory basal area are similar to that on the ponderosa pine basin, but the long term runoff efficiency ratio is only about one half as much (0.14 versus 0.26).

The mixed conifer type on Thomas Creek is located at the highest elevation (8,700 feet) and receives the second highest annual precipitation amount (29.1 inches). Daily snowmelt peaks are barely apparent, indicating much more resistance or longer flow distance to the channel. Overland flow or evidence

of overland flow has seldom been observed on the mixed conifer basins. Mean annual streamflows on these 3 basins are relatively uniform (3.2 to 3.5 inches) even though mean annual precipitation ranges from 25.6 to 31.9 inches. Although some attenuation of the hydrographs on the two higher mixed conifer basins is the result of lower snowmelt rates, the high annual precipitation amounts, longer streamflow period, and lower runoff efficiencies suggest that the major factor is the influence of soil depth and texture.

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Commandra Blister Rust: A Threat to Lodgepole Pine

Brian W. Geils and William R. Jacobi[1]

Abstract--Comandra blister rust is an important canker disease of lodgepole pine in the central Rocky Mountains. Current research is quantifying the risk of serious disease outbreaks and the magnitude of resulting losses. Rust incidence in lodgepole pine stands is related to the distance and direction from the alternate host and average tree height. Projected losses are influenced by both stand and disease conditions such as percent of trees infected and average canker height.

Comandra blister rust *(Cronartium comandrae)* causes stem and branch cankers on several species of pines, including lodgepole pine (Johnson 1986). These cankers are resinous areas which produce orange spores that spread the fungus to an alternate host, but not to other pines. Eventually, a canker girdles the host stem, killing all or part of the crown.

Comandra blister rust occurs throughout most of North America, and is a serious cause of loss in many lodgepole pine forests, especially in the central Rocky Mountains. For example, more than half of the lodgepole pine basal area is in infected trees on the Wind River District of the Shoshone National Forest (Geils and Jacobi 1984).

Comandra blister rust has a complex life cycle with five different spore stages produced alternately on two hosts -- a hard pine and the perennial herb for which the fungus is named, pale comandra *(Comandra umbellata)*.

Objectives

The purpose of this cooperative effort was to develop management tools for predicting:

1. Risk of serious disease outbreaks in stands of lodgepole pine in the Rocky Mountains.
2. Magnitude of damage-related losses to forest resources.

Predicting Risk

Although millions of rust spores are produced annually on each diseased comandra plant, only a few of these spores are likely to infect and subsequently cause damaging cankers on the lodgepole pine host. A risk rating system provides the means to estimate the probability of a rust infestation occurring in a given stand during a fixed period.

A few biological factors are important for determining risk. First, the spores that infect the pine are produced only on comandra plants. These plants occur in sagebrush communities at various distances from the pine stands. The delicate rust spores are wind-dispersed from the comandra plants to pines during rainy days in late summer. And finally, the primary infection sites on pines are young, succulent shoots and needles (Krebill 1968).

We are using historical and on-site weather data to determine the frequency of weather events optimal for spore dispersal and pine infection. These data also provide information on wind direction and speed during spore flight.

The distribution of both host species, disease incidence, and patterns of wind flow are being mapped for the southern portion of the Laramie District, Medicine Bow National Forest, in southeast Wyoming. The lodgepole pine on this district is bordered on the east and west by plant communities in which pale comandra occurs.

Within the narrow range of available stand ages, inventory data for lodgepole pine are being analyzed to correlate stand and site conditions (density, height, age, crown size, site index, habitat type) with disease incidence and severity. Together with location and weather data, this information is being used to predict the gradient of disease intensity and to classify sites for risk of infection.

Our preliminary results indicate that:

1. Pine stands as far as 8 miles from comandra plants can be seriously infected.
2. Spore dispersal from comandra plants to pines seems to be associated with easterly winds during long, rainy periods.

[1]Geils is a Research Plant Pathologist with the Rocky Mountain Forest and Range Experiment Station. Station headquarters is in Fort Collins, in cooperation with Colorado State University. Jacobi is Associate Professor of Plant Pathology, Colorado State University, Fort Collins.

3. Disease incidence increases with average tree height.

Predicting Damage

The growth and yield program RMYLD (Edminster 1978) has recently been modified to account for the effects of comandra blister rust on growth, survival, and merchantable volume of lodgepole pine. Projections from this program can be used to predict the extent of damage resulting from a single infection episode. In the following example, damage is illustrated as loss of merchantable volume in a diseased stand in comparison to a similar healthy stand.

A typical lodgepole pine stand in the Rocky Mountain Region (age 40, site index 60 feet) would contain about 715 trees per acre with an average diameter of 4.4 inches and an average height of 27 feet. Without rust or thinning, the RMYLD program predicts the stand would produce 1070 cubic feet in 700 trees (dbh 5.9 inches) at age 60. The yield predictions suggest that the volume loss (due to tree mortality and growth reduction in surviving trees) by age 60 would depend mainly on the percentage of trees infected at age 40:

20% of trees infected = 5% reduction in stand volume.

40% of trees infected = 20% reduction in stand volume.

60% of trees infected = 40% reduction in stand volume.

80% of trees infected = 60% reduction in stand volume.

Average canker height has an effect on average diameter: low cankers kill infected trees quickly, reducing competition, and improving the individual growth of remaining trees. On the other hand, high cankers kill fewer trees but leave the stand overstocked.

Future Work

Given a different set of initial conditions, losses to comandra blister rust would change from those shown above. Additional work is in progress to project losses with more frequent infection episodes in stands of various site, age, and stocking conditions, and subject to a variety of management practices.

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Sanitation Thinning in Young, Dwarf Mistletoe-Infested Lodgepole Pine Stands

Frank G. Hawksworth, David W. Johnson, and Brian W. Geils[1]

Abstract--A study was begun in 1965 to evaluate sanitation and thinning in young mistletoe-infested lodgepole pine in northern Colorado. After 21 years, the average dwarf mistletoe rating of the treated plots was less than one-fourth that on the untreated plots. Stand projections suggest that in 20 years the merchantable cubic foot yields on the treated plots will be more than three times that on the untreated plots.

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) is the the most serious tree disease agent of lodgepole pine in the Rocky Mountains. This parasite occurs on more than half of the 2 million acres of commercial lodgepole pine forests in the Central Rocky Mountains, and causes an annual volume loss of more than 15 million cubic feet. Dwarf mistletoes are one of the few forest diseases that can be effectively controlled by silvicultural means (Johnson and Hawksworth 1985). However, some early cultural practices actually intensified the problem. For example, harvest operations that left infected residual trees provided ideal conditions for maximum spread and intensification of the disease into young stands.

Thousands of acres of lodgepole pine in the Rocky Mountain Region were partially logged in the 1950's and 1960's and many mistletoe-infected but non- merchantable trees were left standing. These trees now provide a serious source of infection for the young, naturally regenerated stands that have become established beneath them. Sales contracts now call for removal of all infected trees in cutting areas, but vast problem areas of infected reproduction remain in older sale areas.

Study Objectives

The objectives of this joint Rocky Mountain Station-Rocky Mountain Region study are to determine whether young, mistletoe-infested stands can be sanitized and thinned to effectively increase timber yields.

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Methods

Thirty-seven, 1/2 acre plots in 20-, 30-, and 40- year old stands with various intensities of dwarf mistletoe infection were established on the Routt, Arapahoe, and Roosevelt National Forests in 1965 (Hawksworth et al. 1977). Infected overstory trees were removed from each plot. Then about half the plots were sanitized in 1965 and 1968 by cutting all visibly infected trees. These plots, and some mistletoe-free ones, were thinned in 1970 to a 10 X 10 foot spacing (approximately 425 trees per acre). Plots have been remeasured at about 5-year intervals; here we summarize the results after 21 years.

Results and Discussion

Because they present a larger target area for intercepting mistletoe seeds, the larger trees in a stand are typically attacked first (Wicker and Shaw 1967). In this study, the infected trees in 1965 averaged about 1 inch larger in diameter and 3 feet taller than uninfected trees in the same plots. Thus, removing the infected trees initially lowered stand diameter and height.

Before treatment in 1965 the mean stand diameters on treated and untreated plots were essentially the same. In 1970, after sanitation and thinning, the mean diameters on the treated and untreated plots were still about the same because diameter reduction due to removal of the larger, infected trees by sanitation was offset by the removal of smaller, suppressed trees by thinning. By 1986, mean stand diameter for treated plots was 1.7 inches larger than for untreated plots. Simulations from the RMYLD growth and yield program (Edminster 1978) project, that in another 20 years, the mean tree diameter on the treated plots will be 2.5 inches greater than that on the untreated plots.

The proportion of trees infected in untreated plots increased from 28 percent in 1965 to 53 percent in 1986. In treated plots, 30 percent of the trees were infected in in 1965; this level was reduced to essentially zero as all visibly infected trees were removed in 1965 and 1968. In 1986, 26 percent of the trees were infected, or less than half that in the untreated plots.

Differences in ratings of average stand dwarf mistletoe intensity (6-class DMR system, Hawksworth 1977) between untreated and treated plots from 1965 to 1986 were even more marked: stand DMR increased from 0.6 to 1.4 in the untreated plots, whereas it fell from 0.6 to 0.3 in the treated plots. Such low levels of infection on treated plots will result in little effect on tree growth for several decades.

Projections using the RMYLD growth and yield simulation program suggest that volume growth in treated stands will be much greater than that in the untreated stands. For example, the treated stands will produce an estimated 2320 merchantable cubic feet per acre in 60 years, compared to a projected 680 merchantable cubic feet per acre in the untreated stands. These preliminary results confirm that sanitation and thinning can significantly increase yields in young, mistletoe-infested lodgepole pine stands.

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Long-Distance Dispersal of Lodgepole Pine Dwarf Mistletoe

Frank G. Hawksworth, Thomas H. Nicholls, and Laura M. Merrill[1]

Abstract--A total of 721 birds and 290 mammals were captured at the Fraser Experimental Forest during the autumns of 1982, 1983, and 1986 and examined for seeds of *Arceuthobium americanum*. Eighty one mistletoe seeds were found on 75 trapped animals of 14 species (10 birds and 4 mammals). The gray jay and least chipmunk were the most common transporters of seed. During the peak period of seed dispersal in 1982, 22% of the individual birds and 20% of the individual mammals carried mistletoe seeds. In a 70-year-old stand of lodgepole pine that was otherwise mistletoe-free, we found 1.7 isolated infection centers per hectare, concentrated primarily near large stand openings. Such openings are apparently attractive habitats for birds that may transport dwarf mistletoe seeds for long distances. Thus, there is some evidence that these animals are vectors of dwarf mistletoe seeds, and that they are occasionally responsible for long-distance spread of the parasite.

Dwarf mistletoe seeds are primarily dispersed by an explosive fruit mechanism that projects them for up to several meters (Hawksworth and Wiens 1972). Many observations, however, suggest that dwarf mistletoe seeds are sometimes transported over greater distances than can be explained by explosive fruits (Nicholls et al. 1984). There are a few quantitative studies on dispersal of dwarf mistletoes by birds: *Arceuthobium pusillum* on black spruce *(Picea mariana)* in Minnesota (Hudler et al. 1974 and Ostry et al. 1983) and *A. vaginatum* subsp. *cryptopodum* on ponderosa pine *(Pinus ponderosa)* in Colorado (Hudler et al. 1979).

Hudler et al. (1979) studying dispersal of *A. vaginatum* subsp. *cryptopodum* on ponderosa pine in central Colorado, found 32 isolated ("satellite") centers in 194 ha of otherwise mistletoe-free forest (0.16 centers/ha). Satellite centers contained from 1 to 175 infected trees covering 0.3 ha. The most isolated center was 450 m from the nearest potential seed source.

Ostry (1978) examined black spruce stands infested with *A. pusillum* in northern Minnesota. He found 12 satellite centers in 188 ha of otherwise mistletoe-free forest, or 0.06 centers/ha. The centers contained from 1 tree to more than 100 trees covering 0.15 ha. The most isolated center was 250 m from the nearest potential seed source.

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To better understand long distance dispersal of dwarf mistletoe seeds, we conducted two studies on lodgepole pine dwarf mistletoe *(Arceuthobium americanum)* at the Fraser Experimental Forest near Winter Park, Colorado. Our objectives were to: (1) identify potential avian and mammalian vectors[2] of dwarf mistletoe seeds; and (2) determine the distribution of isolated infection centers in a lodgepole pine stand that was otherwise disease-free.

Methods

Seeds on Animals

This study was conducted during August and September (the period of seed dispersal for *Arceuthobium americanum*) of 1982, 1983 and 1986. Detailed methods appear in Nicholls et al. (1984). The lodgepole pine forest studied is mainly of the *Abies lasiocarpa/Vaccinium scoparium* habitat type. Birds and mammals were captured with cell traps or mist nets, examined, and the number and location of seeds adhering to their bodies recorded (Nicholls et al. 1984). Seeds were tested for viability with tetrazolium chloride (Scharpf 1970).

Birds were banded and mammals were ear-tagged so that individuals could be identified upon recapture. Movements of animals within the study area were monitored by retrapping, color marking, or radio telemetry (Nicholls et al. 1984).

[2]We use the term "vector" as "an animal able to transmit a pathogen" (D. L. Hawksworth et al. 1983).

Timing of dwarf mistletoe seed dispersal throughout August and September was monitored by making daily seed counts on muslin seed traps placed on the ground near infected trees at three different elevations (9,000, 9,400 and 10,200 feet). These seeds were also checked for viability using the TTC test.

Satellite Centers

A 145-acre (58.7-ha) study area in the *Abies lasiocarpa/ Vaccinium scoparium* habitat type was examined for satellite infection centers. The stands were mostly even-aged, large pole (20-40 cm d.b.h.), lodgepole pine about 70 years old that originated after severe fires in about 1910. The area contained a few remnants of the original old-growth lodgepole pine, with scattered stands dominated by aspen *(Populus tremuloides)* or Engelmann spruce *(Picea engelmannii)*. The area was examined on a 1 chain (20 m) grid. At each point, lodgepole pines within a 1/2-chain (10 m) radius were examined for isolated infected trees.

In most cases, satellite centers were more than 20 m from the closest seed source. In four cases, however, infection centers were less than 20 m away from the closest seed source but they were considered to be satellites because there were non-infected screen trees between them and the nearest infection source. In all cases where satellite centers were found, there were no stumps of remnant trees that could have provided an infection source.

When satellite infection centers were found, the following data were recorded:

1. Distance and direction to closest potential seed source.
2. Stand structure surrounding the center: (1) within stand (no opening), (2) small opening = no trees in less than 1/3 of the sector of a 10 m radius circle around the center, or (3) large opening = no trees in more than 1/3 of the sector.
3. Number of infected trees.
4. Dwarf mistletoe rating (6-class system; Hawksworth 1977).

The infection that appeared to be the oldest in each center was examined in the laboratory to determine the approximate date of origin based on detection of mistletoe sinkers or xylem stimulation (Scharpf and Parmeter 1966).

The distribution of satellite centers was analyzed using the Raleigh test for concentration, as outlined by Batschelet (1965).

Results

Seeds on Animals

A total of 721 birds (including retraps = IRT) of 31 species and 290 mammals (IRT) of four species were captured. Of these, 10 bird and 4 mammal species had seeds of A. americanum on their bodies (table 1): 29 dwarf mistletoe seeds were found on the fur of 29 mammals and 52 seeds were found on the feathers of 46 (fig. 1). The most common bird species with seeds on its feathers was the gray jay (3 times more seeds than the next closest species); the least chipmunk was the most common mammalian transporter of seed, with over eight times more seeds on its fur than the next closest species. During a 16-day period in 1982 when seed dispersal was at a maximum, 22 percent of the birds (N = 55 IRT) and 20 percent of the mammals (N = 80 IRT) captured had seed.

Table 1.--Animals captured at the Fraser Experimental forest and found to have seed of A. americanum in their fur or feathers.

Animal species with seed	Number trapped and examined	Number with seed	Number of seed
Gray Jay (Perisoreus canadensis)	162	22	25
Steller's Jay (Cyanocitta stelleri)	29	5	8
Mountain Chickadee (Parus gambeli)	88	5	5
Gray-headed Junco (Junco hyemalis)	123	3	3
Audubon.s Warbler (Dendroica coronata)	62	3	3
American Robin (Turdus migratorius)	35	2	2
Northern Saw-whet Owl (Aegolius acadicus)	9	2	2
Hermit Thrush (Catharus guttatus)	75	2	2
Three-toed Woodpecker (Picoides tridactylus)	9	1	1
Townsend's Solitaire (Myadestes townsendi)	4	1	1
Ten bird species	596	46	52
Least Chipmunk (Eutamias minimus)	254	24	24
Golden-mantled Squirrel (Citellus lateralis)	20	3	3
Red Squirrel (Tamiasciurus hudsonicus)	15	1	1
Pine Marten (Martes americana)	1	1	1
Four mammal species	290	29	29

Five gray jays radio-tracked in 1983 frequently moved back and forth between infected and healthy stands of lodgepole pine. Some of these birds were known to have seeds on their feathers when they were radio-tracked. Details on gray jay movements and home ranges will be discussed in a subsequent paper.

Birds were not observed eating mistletoe seed; rather, they acquired seed when foraging for food in infected trees when seeds were being explosively discharged. The seeds, sticky with viscin, easily stuck to feathers. Most seeds were found

around legs, on the breast, and under wings and tail. Of 20 seeds tested with TTC, 65 percent were viable.

Both resident and migratory birds (Alexander et al. 1985) were captured with seeds on their feathers. Of the 10 birds with seed, only 3 (gray jay, mountain chickadee, and three-toed woodpecker) are year-round residents. This suggests that seeds could be disseminated over short distances by resident birds and over long distances by migratory birds.

Birds were not observed feeding on mistletoe plants, but one least chipmunk was seen feeding on dwarf mistletoe fruits for about 20 minutes; subsequently it was seen to have 5 seeds on its fur.

During 1983, when the seed dispersal was measured on traps at 9,000, 9,400 and 10,200 feet, the overall seed dispersal period lasted about 6 weeks and began at the lowest elevation in mid-August. At each site, seed dispersal lasted about 4 weeks, and the peak dispersal was about a week later for each increase of about 500 feet in elevation. Based on TCC tests, 65% of the seeds sampled (N= 66) from the traps were viable, the same percentage as for seeds found on animals.

Figure 1.--Dwarf Mistletoe seed sticking to the (A) tail feather of a Steller's jay, (B) tail of a least chipmunk.

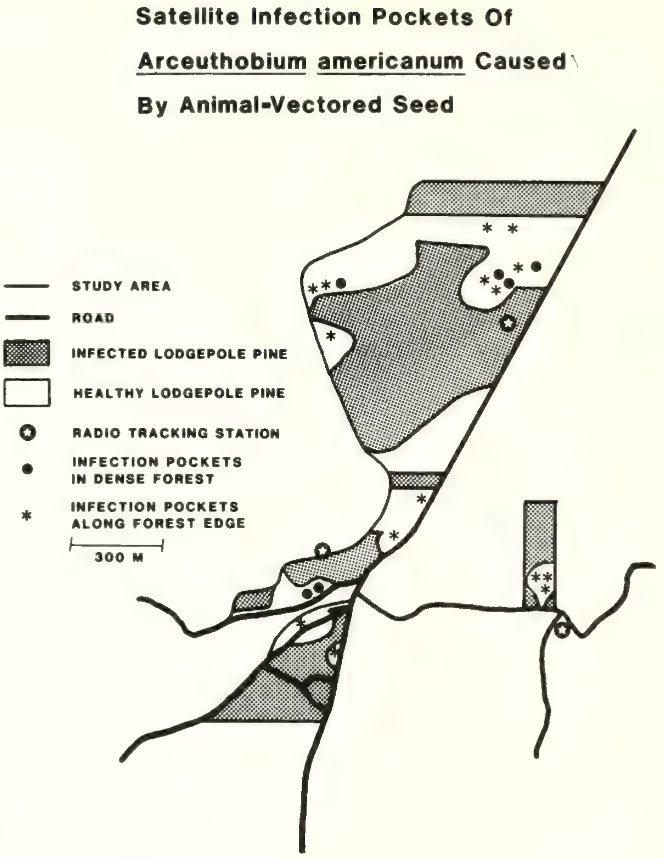

Figure 2.--Satellite infection pockets of Arceuthobium americanum such centers presumably developed from animal-dessiminated seed, Fraser Experimental Forest, Colorado.

Satellite Centers

A total of 1,450 plots were established. Of the 58.7 ha area surveyed, 8.8 ha were not in lodgepole pine (aspen, Engelmann spruce, or non-forest). Of the 49.9 ha lodgepole pine area, 35.3 ha were in stands generally infested by mistletoe. A total of 361 plots fell in the 14.6 ha. of primarily mistletoe-free lodgepole pine where, 25 satellite infection centers were found (fig. 2). Of these, 4 contained infected trees that predated the establishment of the 70-year old stand, but 21 centers (1.4/ha.) were younger than the age of the stand (table 2).

Satellite infection centers ranged from 12 to 65 m (average 27 m) away from the closest potential sources of inoculum. The centers had from 1 to 10 trees (average 3.5) and infection intensity was generally light, with dwarf mistletoe ratings of 1 to 3. The Raleigh test for concentration (Batschelet 1965) showed no significant trend for direction to the closest potential seed source. However, there was a tendency for satellite centers to become established at the edge of large stand openings: 11 of the 21 centers were adjacent to such natural stand openings or along old phone line clearings or logging roads:

Table 2.--Characteristics of 21 dwarf mistletoe satellite centers in a lodgepole pine stand at Fraser Experimental Forest, Colorado.

Satellite no.	Infected trees (no.)	Aver. DMR of infected trees	Distance to closest seed source	Direction to closest seed source	Degree of stand opening*	Age of oldest infection (years)
1	1	1.0	29.0	WNW	1	8
2	1	1.0	12.2	NW	1	19
3	6	1.3	42.0	NW	3	17
4	1	3.0	13.7	NE	3	8
5	2	1.0	21.3	W	1	20
6	5	1.2	28.0	SSW	2	13
7	4	1.3	47.3	WSW	3	14
8	1	1.0	25.0	NE	2	4
9	3	1.0	26.2	N	1	17
10	10	2.3	23.2	N	2	43
11	4	2.0	14.9	NE	3	28
12	1	1.0	20.1	N	2	13
13	2	1.0	65.2	NNE	1	20
14	2	3.0	64.0	S	3	50
15	1	1.0	17.4	NE	3	18
16	8	1.1	35.1	N	1	27
17	9	1.9	33.5	SW	3	39
18	6	1.2	39.3	W	3	20
19	7	1.7	53.4	ESE	3	22
20	10	1.2	43.3	NNE	3	34
21	3	1.0	25.3	E	3	19
Mean	3.5	1.4	32.3	-	-	22

1 = within stand, 2 = small opening, 3 = large opening.

	Number of satellite centers
Within stand	6
Small openings	4
Large openings	11
Total	21

The age of the oldest infection found in each center ranged from 4 to 50 years, but most were between 11 and 20 years old:

Oldest infection (years)	Number of satellite centers
4-10	3
11-20	12
21-30	2
31-40	2
41-50	2
Total	21

No relationship was found between the age of satellite centers and the distance to the nearest potential seed source.

Discussion

There are several reports of dwarf mistletoe infection centers that originated from other than explosively discharged seeds, and are not remnants of fire escapes (Hawksworth and Wiens 1972). These observations have elicited much speculation as to the factors responsible for long-distance spread. Dissemination by birds or animals would explain the origin of satellite infection centers far removed from main infection centers. That these animals may serve as vectors is logical because the seeds will generally stick to anything they hit. Animals can come in contact with mistletoe seeds when foraging for insects, eating mistletoe shoots or fruits, storing food, or nesting in mistletoe brooms. Furthermore, dwarf mistletoe seeds removed during the animals' regular grooming can cause infection if the seeds are viable and deposited on susceptible parts of host trees.

For animals to transport dwarf mistletoe seeds and establish new infection centers and thus serve as vectors, certain criteria must be met (adapted from Zilka and Tinnin 1976): (1) the seed must become attached to the animal; (2) the seed must arrive in viable condition on a susceptible host; (3) the seed

must come in contact with susceptible parts of the host; and (4) both male and female plants must become established; or, if only female plants, they must be close enough to male plants to receive pollen.[3] Because of these specific requirements, mistletoe infections arising from animal-disseminated mistletoe seed are probably infrequent. The scattered cumulative infections that develop over long periods of time, however, coupled with the spread of seeds from the explosive fruits after the centers are established, may occur frequently enough to be of concern in the effective control of this parasite.

This study has documented that animals can transport dwarf mistletoe seeds, and at least two studies (Hudler et al. 1979, Ostry et al. 1983) have shown that birds can inoculate susceptible trees. Thus, these studies indicate that animals can serve as vectors for dwarf mistletoe. The movements and behavior of the different species play a key role in how and where dwarf mistletoe seed is transported. In general, most birds do not eat mistletoe seeds, or, if they do, the seeds are not passed through the digestive tract in viable condition (Hudler et al. 1979, Zilka and Tinnin 1976, Ostry et al. 1983). All studies to date show that viable dwarf mistletoe seeds are transported only on the external surfaces of animals.

The distance seeds can be transported by animals depends on their home range size is and whether they are migratory or resident. Because of their relatively small home ranges, mammals are probably important only in local spread and intensification. Resident birds, such as the gray and Steller's jays, mountain chickadees, and gray-headed juncos, would also be most important in local and short-distance spread of dwarf mistletoe. This study and others (Hudler et al. 1974, Ostry et al. 1983) found the gray jay to be the most common vector of mistletoe seeds.

Migratory birds, such as the warblers (*Dendroica* spp.), robin, and hermit thrush, may be more important in long-distance spread of dwarf mistletoes. Many dwarf mistletoe species release seed during late summer and fall when these birds are migrating southward. Because birds that select a lodgepole pine habitat in one area may choose the same habitat in other areas during migration, seeds picked up in an infected stand could be deposited in a similar stand some distance away. This habitat specificity is important and increases the chance that a successful infection will result, because dwarf mistletoes are generally host specific (Hawksworth and Wiens 1972).

Least chipmunks and golden-mantled squirrels spend most of their time on the ground, where they probably picked up seeds already released from the fruits. In contrast, red squirrels spend proportionately more time in the trees cutting down cones and storing mushrooms in dwarf mistletoe witches brooms and other branches. They were frequently seen brushing against mistletoe shoots during these activities. In contrast to the birds in this area, the home ranges of these mammals is small, so they may be involved only in local dissemination of dwarf mistletoe.

Highly specific requirements must be satisfied before a successful dwarf mistletoe infection can occur. Once infection occurs, several years must pass before the life cycle of the pathogen can be completed to establish an infection center. Because of these highly specific requirements, infections that develop from animal-disseminated seed are probably infrequent. The cumulative establishment of scattered infection centers over long periods of time, however, and subsequent local dispersal, can accelerate and intensify the spread of dwarf mistletoes.

The number of satellite centers (1.4 per ha) found in this study is greater than that reported for other dwarf mistletoes (Hudler et al. 1979, Ostry 1978), and suggests that long-distance dispersal in lodgepole pine may be more common than has been generally recognized.

A factor that may tend to favor animal dispersal of mistletoe in lodgepole pine is that host tissues up to 60 years old are susceptible to infection by *A. americanum* (Hawksworth 1954). This age is in marked contrast to most dwarf mistletoe hosts, where infection typically takes place only through tissues less than 5 years old (Hawksworth and Wiens 1972). A possible result is that larger animals may serve as vectors, since potential seed transport would not be limited to young, needle-bearing tissues. For example, only small birds (chickadees and nuthatches) are implicated as vectors of *A. vaginatum* on ponderosa pine (Hudler et al. 1979), where most infection occurs on needle-bearing twigs 1-3 years old (Hawksworth 1961).

Most of the satellite centers were from 11 to 20 years old; thus they became established when the stands were from 50 to 60 years old. This age distribution supports our observations that satellite centers are rather rare in young (less than 50-year-old), even-aged stands of lodgepole pine established in clearcuts or regenerated burns. Taylor and Barmore (1980) studied the avifauna in relation to post-fire succession in lodgepole pine in Yellowstone and Grand Teton National Parks, Wyoming. They found marked variation in bird activity with time since the initial burn:

Years after fire	Activity
1-4	Intense bird activity, particularly woodpeckers in trees killed by the fire.
5-30	Very little bird activity; only white-crowned sparrows abundant.
30-50	Bird activity greatly increased, about 13 species are common.
50-100	Species guilds about the same as at 30-50 years, but lower density. Gray jays, not listed at 30-50 years, now common.

[3]The effective distance of pollen dispersal in the dwarf mistletoes has not been determined, but pollen dispersal distances for A. americanum of 510 m have been reported in Colorado (Copolla, in press) and 400 m in Manitoba (Gilbert and Punter 1984).

Studies in Colorado confirm that there are few birds in young lodgepole pine stands (Hein 1980, Mullis 1978). Gray jays, and to a lesser extent Steller's jays and mountain chickadees, were the main bird species transporting seeds of lodgepole pine dwarf mistletoe at the Fraser Experimental Forest. The above studies suggest that these species find young stands in clearcuts or burns (younger than 30-50 years) less attractive, which may explain why few satellite centers become established in such young stands. The tendency for satellite centers to become established most frequently near the edges of large stand openings may be due to the birds' preference for this habitat (Thomas et al. 1979).

Although satellite centers may become more common in older lodgepole pine stands (over 50 years), their low frequency and low mistletoe intensities suggest that their effects on stand volume growth will be minimal if stands are harvested by age 100-120. Thus, potential mistletoe spread into clearcut areas is very low, and clearcutting to minimize damage due to dwarf mistletoes is still a sound silvicultural management practice in mature lodgepole pine (Hawksworth and Dooling 1984).

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A System That Monitors Blowing Snow in Forest Canopies

R. A. Schmidt and Robert L. Jairell[1]

Abstract--An electronic system that connects a desktop computer (PC) to tower-mounted arrays of snow particle counters provides a new approach to an old problem--why more snow accumulates in small openings than in the surrounding forest. Each photoelectric sensor generates a pulse for a particle passing through its light beam. These are counted by a microprocessor system that passes the sums to the PC. Preliminary measurements in both a clearing and the forest upwind show counts increasing with height in the 15-m region centered near the mean canopy height (18 m).

Why do small forest clearings accumulate more snow than adjacent stands? This question has puzzled researchers since studies began at the Fraser Experimental Forest in Colorado. They developed two explanations: (1) snow trapped by the forest canopy (interception) evaporates in place, reducing snowpack on the forest floor, and (2) wind guides more snowfall (including interception) into the clearings (aerodynamic redistribution).

Interception was first favored as the likely explanation. Goodell (1959) measured evaporation of intercepted snow, and called for detailed analytical studies of the process (Goodell 1963). However, intensive measurements of snowpack on the Fool Creek watershed suggested that timber harvest did not increase total snow accumulation, compared to the East St. Louis control watershed (Hoover and Leaf 1967). This evidence supported the aerodynamic redistribution hypothesis, because reducing interception loss by timber harvest should increase total snow accumulation.

Researchers led by Charles Troendle have continued to measure the peak water equivalent of snow on Fool Creek and East St. Louis. With precision increased by a longer measuring period, it now appears that total snow accumulation on Fool Creek did increase about 9% after harvest. This increase approaches the 12% increase Hoover and Leaf (1967) said was expected, assuming all increased snowpack (and thus streamflow) resulted entirely from reduced interception loss (Troendle and King 1985).

Analytical experiments on the evaporation of blowing snow in the plains environment (Schmidt 1972, 1982; Tabler and Schmidt 1972; Tabler 1975), show how strongly surface area affects the process. The results support the likelihood that evaporation of intercepted snow explains the increased accumulation in clearings. Snow held on branches presents a huge extension of surface area exposed to moving air, compared to the snow surface in the clearing.

Intensive snowboard measurements reported by Wheeler (in press) for the 1985-86 winter, demonstrate that accumulation differences between clearing and forest (1) usually occur during storms, not between storms, and (2) are inversely related to wind speed during the storm. Both results, but especially the latter, argue against aerodynamic redistribution as the main cause of the difference.

The electronic system described here is a step toward the detailed studies of the distribution and evaporation of snowfall in forest canopies and clearings called for by Goodell in 1963. This paper presents a method of counting precipitating snow crystals, and shows example results from a cut block on the Fraser Experimental Forest.

Study Site

The cut block, 80m wide in a stand of mature spruce and lodgepole pine with an understory of subalpine fir, extends 100m down a north-facing slope (40%) draining into West St. Louis Creek, in the Fraser Experimental Forest (fig. 1). The block is near Short Creek, in the center of Section 8, T2S, R76W, at 2925m elevation (9600ft), 106°54' west longitude, 39°52'30" north latitude. Wind during storms is most often from the west to northwest at this site. Troendle designed the block and erected towers for these experiments, with the assistance of Manual H. Martinez, who also constructed the tower wiring harnesses and placed the cables between the

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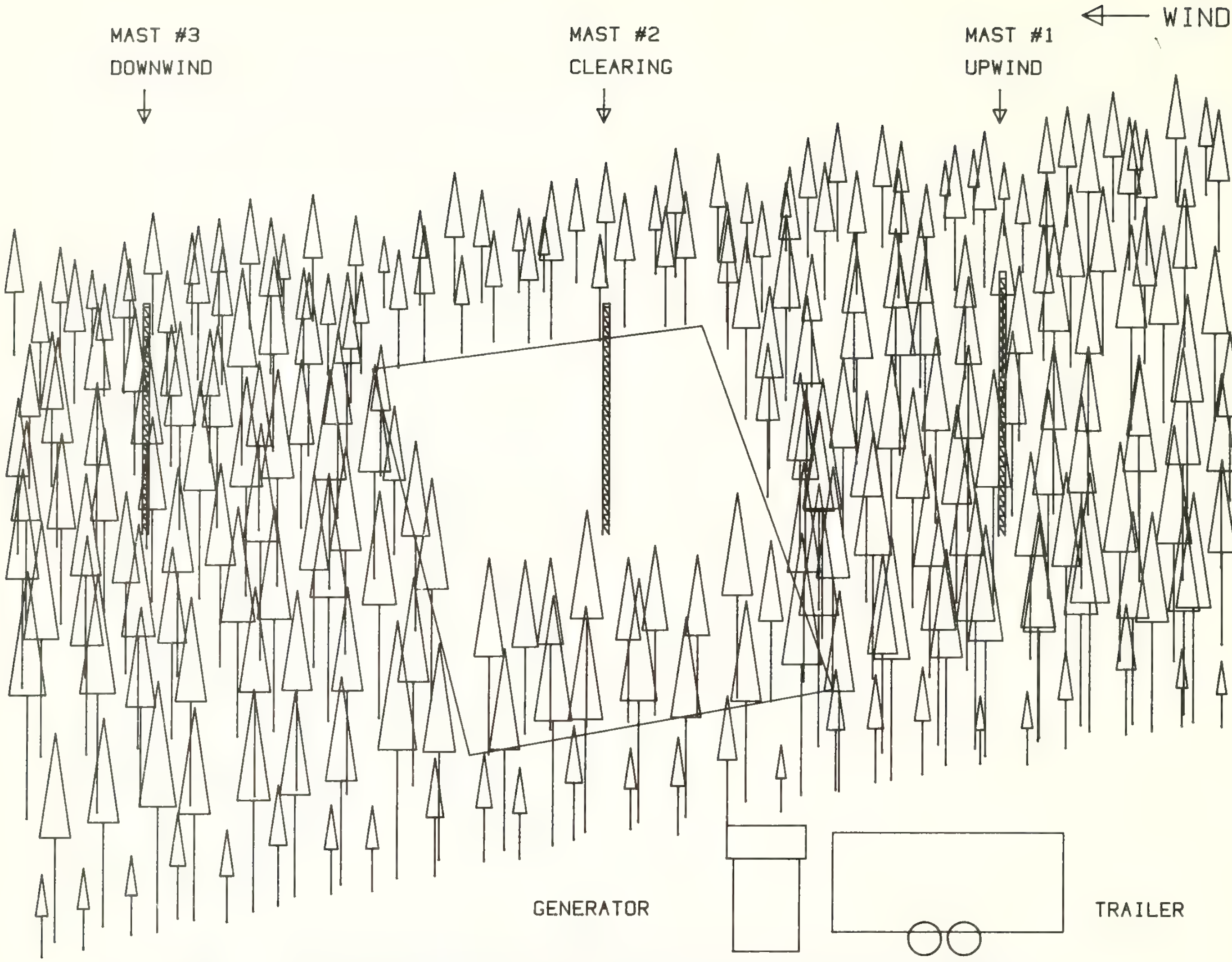

Figure 1.--The experimental site on West St. Louis Creek includes a cut block in a mixed stand of spruce, fir, and lodgepole pine. This clearing is 80m wide and extends 100m down a north-facing 40% slope. Towers are located (1) upwind, (2) center, and (3) downwind of the clearing, with 85m separating towers 1 and 2.

towers and the trailer. A 27m tower supports instruments in the center of the clearing, 40m east from the upwind edge. In the upwind forest, 85m from the clearing tower, a 34m tower extends about 16m above the average canopy height of 18m. A third tower in the forest downwind of the clearing was not used in initial experiments with this system. (All three towers carried triaxial anemometers at two levels as part of another study by David Miller.)

For the first tests, six sensors were uniformly spaced 3m (10ft) apart between 15 and 30m on the upwind mast during several storms. The lowest two sensors were below the average canopy height. All sensors were then deployed on the clearing tower, again at the same spacing, between 11 and 26m above the snow surface, during two storms. Finally, three sensors measured snowfall at the highest (#1), lowest (#6), and #4 position on both towers, allowing comparison of simultaneous counts in the forest and clearing.

Counting Snowflakes

The system (fig. 2) consists of the sensors mounted on towers, wiring harnesses on each tower to provide signal and power interconnections, cables from each tower to a small instrument trailer below the clearing, counting circuits that sum each sensor's signals, and the desk-top computer (PC). A propane-driven generator provides satisfactory electric power, since the system operates only during events when an observer is at the site.

The snow sensor, called a snow particle counter (SPC), is a device developed to measure the number and size of particles moving in blizzards (Schmidt 1977). Two phototransistors sense shadows cast by particles passing through a light beam (fig. 3), producing voltage pulses that are amplified at the sensor and sent to counting circuits. Pulse amplitude is related to the size of the particle's shadow. (For these initial

experiments, the system does not extract the information on particle size, however.)

The microprocessor system (fig. 2) passes counts from runs, of 1 to 10 min duration, to the computer for printing and storage on disk. Using an internal analog-to-digital converter, the computer also monitors wind speed and direction from an anemometer and vane mounted at 10m on the clearing tower.

To assure comparable sensitivity, each SPC is calibrated by spinning a wire through the beam and adjusting amplification for a standard output, measured as peak-to-peak pulse amplitude on an oscilloscope. This was accomplished before and after each day's experiment for the first few events, until experience showed such frequent calibrations were unnecessary. After that, calibrations were checked when some change was made in the setup, such as moving sensors between towers. (Miller equipped each tower with a safety rope and halyard system, which greatly facilitated calibration of the SPC's.)

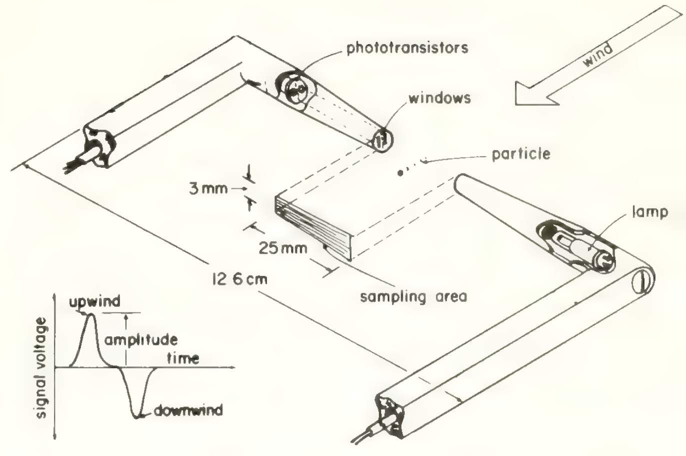

Figure 3.--The snow particle counter (SPC) senses the shadow of particles passing through the light beam, producing amplified voltage pulses. With two windows, estimates of particle speed are possible (from Schmidt 1977).

Example Results

Although the objective of initial experiments was only to test the measurement technique, transfer from our laboratory to Dr. Troendle's study site proceeded so smoothly that he was able to test two hypotheses concerning the snow accumulation problem during March, 1987. Details will be reported elsewhere, but the hypotheses were: (1) There is no significant difference in particle counts between levels on a tower, and (2) There is no significant difference between average counts at each tower.

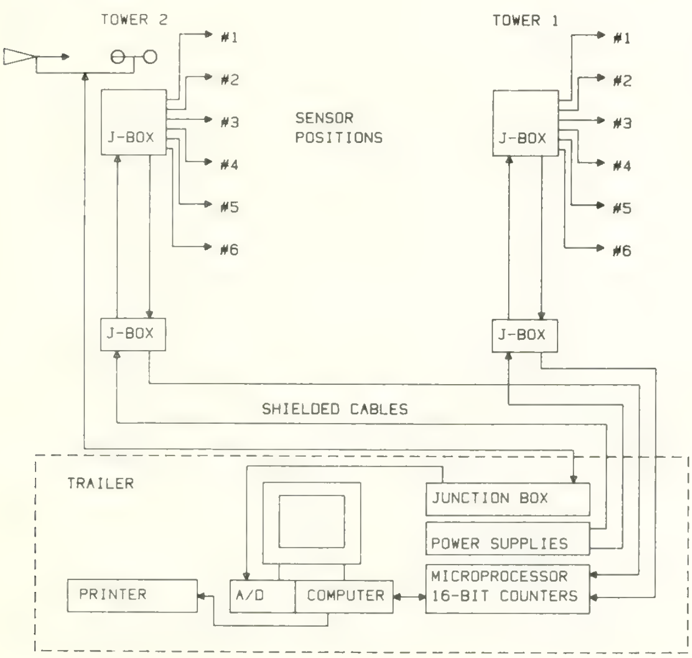

Figure 2.--Signals from each SPC on the towers are summed and transferred to the computer by a microprocessor system. An analog-to-digital converter in the computer measures voltages from wind speed and direction sensors at the 10-m height on tower 2, in the clearing.

Figures 4a and 4b show typical examples of counts when all sensors were on one tower. Counts were normalized by the mean count of all sensors for each run, and heights were normalized by the midpoint and spacing of the sensor array. Figure 4c is a comparison of counts during a run with three sensors at each tower. We found no large differences in average counts between towers.

Although designed to measure the smaller particles and greater frequency of drifting in blizzards, the SPC's provided useful and apparently consistent measures of snowfall under light winds in a forest canopy.

Plans

If these preliminary results withstand tests for statistical significance, it appears that particle count usually increases with height both in the clearing and above the canopy (although the opposite gradient was occasionally observed). Average counts seem to be about the same at each tower, however. The next question is, "Are particle sizes similar?"--that is, do these counts represent the same mass flux. We are adding electronics to determine size distributions for experiments during the 1987-88 winter.

To explain the decrease in count within the forest seems simple-- interception. Yet a similar gradient of particle numbers appears in the clearing measurements. Does this reflect an aerodynamic effect? Anemometers at each SPC location will help estimate particle trajectories in upcoming experiments with this system.

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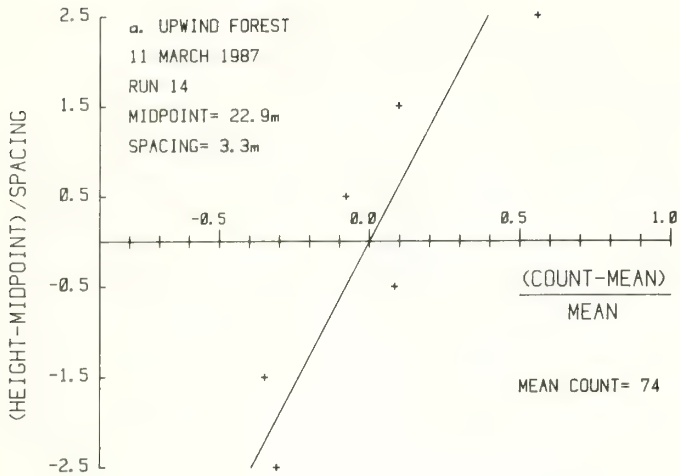

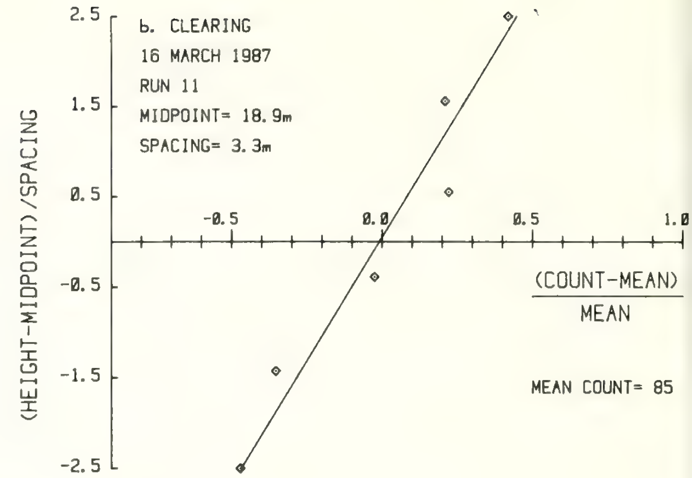

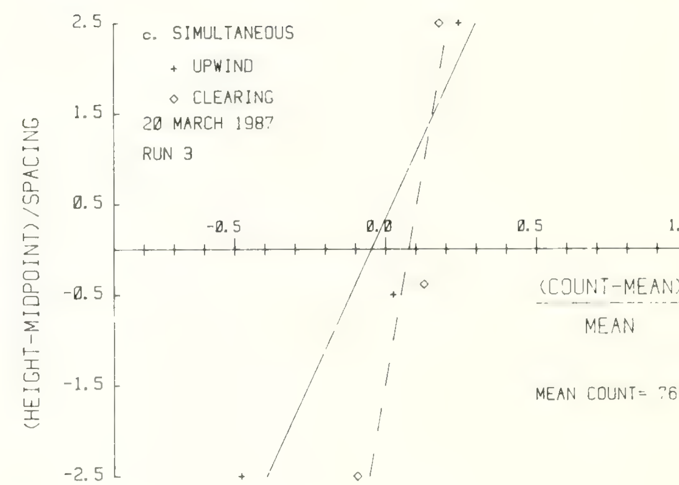

Figure 4.--Example plots of particle counts during 5-min runs with six sensors at (a) tower 1 (upwind) and (b) tower 2 (clearing). Three sensors at each tower gave the counts in (c). Both count and height are normalized by the respective means.

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Temperature Gradient Driven Vapor Transport in Snow

Richard A. Sommerfeld[1]

Snow is a good insulator. The first snow layer of the season traps the heat that has been stored in the ground during the summer. This heat is slowly released to flow through the snow to the colder, upper surface of the snowpack. Part of the heat flow is carried by water molecules that move from the warmer to the colder grains. This temperature driven vapor flow causes extensive recrystallization in a process called temperature gradient metamorphism. Normal temperature fluctuations, and the snow's layered structure complicate the process. However, a simple system with a constant difference across a uniform snow layer can provide the information necessary for understanding the more complex system. Such a simple system is easily maintained in a cold laboratory.

Two different size scales are important in a quantitative understanding of the temperature gradient (TG) metamorphism caused by the temperature gradient across a snow layer. At the macroscopic level, the snow layer can be treated as a continuous infinite slab. The one dimensional temperature gradient causes a vapor pressure gradient across the slab and the vapor diffuses across the layer according to Fick's first law,

$$J = - D_{eff} \frac{\partial P}{\partial P} \qquad [1]$$

where J is the mass flow rate, D_{eff} is the effective diffusion coefficient of water vapor in snow, P is the water vapor pressure, and z is the vertical coordinate, perpendicular to the slab. Geometrical factors discussed below raise the possibility that D_{eff} is not equal to the diffusion coefficient of water vapor in air (D_w) but that

$$D_{eff} = K_s D_w \qquad [2]$$

where K_s depends on the microstructure of the snow.

It is easy to measure the temperature gradient through a snow slab, and to calculate the vapor pressure gradient from that. Normally, one would measure Deff by measuring the flow rate under a carefully controlled temperature gradient and thereby determine K_s. However, this is impossible in snow.

One serious problem in determining K_s is caused by the fact that the heat and mass flow are coupled. The temperature gradient provides the driving force for the mass flow which, because of the transfer of heat of fusion, affects the temperature gradient. This causes a curvature in the temperature gradient. The curvature also complicates the vapor pressure gradient (fig. 1). Further complications arise from the microscopic complexity of the ice network that makes up the snow. For example, it is not possible to determine independently the quantity of heat conducted through the ice so that the amount transferred by the mass flow could be determined.

To understand the microscopic complexity, it is necessary to understand that the microstructure of snow can include three types of grains. A "snow grain" can only be defined approximately as the obvious subunit at the microscopic level in snow (Sommerfeld and La Chapelle, 1970). While this definition is imprecise, the concept is nonetheless useful. Snow grains can be classified by their type of attachment in the snow microstructure as shown in figure 2 (Kry 1975). A grain with one bond is called a branch grain, with two bonds a chain grain, and with more than two bonds, a link grain. Other types of grains might be categorized (Gubler 1978), but this idealization is relatively simple and, as we will see, is sufficient for understanding TG metamorphism.

De Quervain (1973) shows a geometry (fig. 3) in which branch grains are important. Because the thermal conductivity of ice is about 100 times the thermal conductivity of air, the temperature gradient between branch grains and other grains will be increased. The increased gradient results in preferred growth sites such that some grains grow at the expense of others. Sommerfeld (1983) showed that about 50% of the grains disappeared during TG metamorphism. He pointed out that the disappearance of grains was a necessary consequence of the conservation of mass.

Yosida and colleagues (1955) pointed out that vapor transport in snow is different from that in other systems in that the solid and the liquid are the same substance. He termed this type of transport "hand to hand" because each grain receives water molecules "handed" from below and "hands" them to the grain above. Since it is not possible to distinguish among water molecules, the transport appears to proceed without obstruction by the solid phase. However, Yosida and colleagues (1955) modeled snow as a uniform distribution of grains without connection, ignoring some of the important microstructural features.

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Giddings and La Chapelle (1962) used a continuum model which also ignored important aspects of the microstructure. Like de Quervain (1958, 1973), they did not include conservation of mass and thus had an inaccurate estimate of mass flow.

Colbeck's (1983) calculations of vapor flow rate were based on a uniform distribution of ice spheres, and ignored the "hand to hand" character of the process and conservation of mass.

Gubler's (1985) model assumed that the "hand to hand" process was not important because the preferred growth sites were "shielded" from the grains above. Gubler (1985) did not present any data to support this assumption. "Shielding" is not evident in the movie sequences of TG metamorphism filmed by Kuroiwa (1975).

The first model to include all the important features of TG metamorphism mentioned above was that of Christon et al. (in press). They used a finite element model that idealized the snow as a two dimensional grid with various orientations of branch grains. Their model conserved mass and solved the coupled heat and mass flow problem. Depending on the branch grain geometry, Christon et al. calculated flow rate enhancement factors (K_s) up to 2.5.

Measurements of K_s or D_{eff} are necessary to test the above model. D_{eff} can be measured using isotopic fractionation of the naturally occurring stable isotopic species in the snow, HDO and $H_2{}^{18}O$. Primarily because of their larger molecular weights, these species have lower vapor pressures and lower diffusion coefficients than normal H_2O. If the snow can be considered as a continuum, the following equation is applicable,

$$\frac{d\left[m_{iso} / m_{H_2O}\right]}{dt} = \left[\frac{1}{m_{H_2O}}\right] \cdot \left[\frac{dm_{iso}}{dt} - \frac{m_{iso}}{m_{H_2O}} \frac{dm_{H_2O}}{dt}\right]. \qquad [3]$$

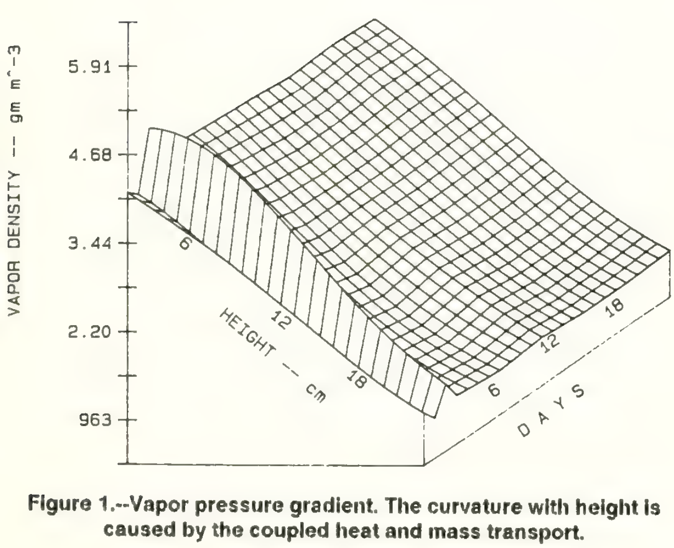

Figure 1.--Vapor pressure gradient. The curvature with height is caused by the coupled heat and mass transport.

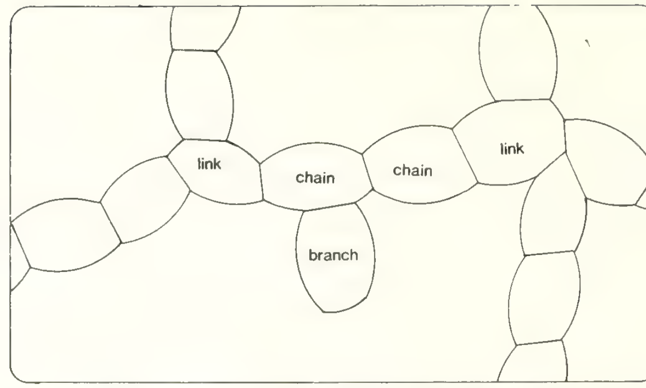

Figure 2.--Grain types in snow after Kry (1975).

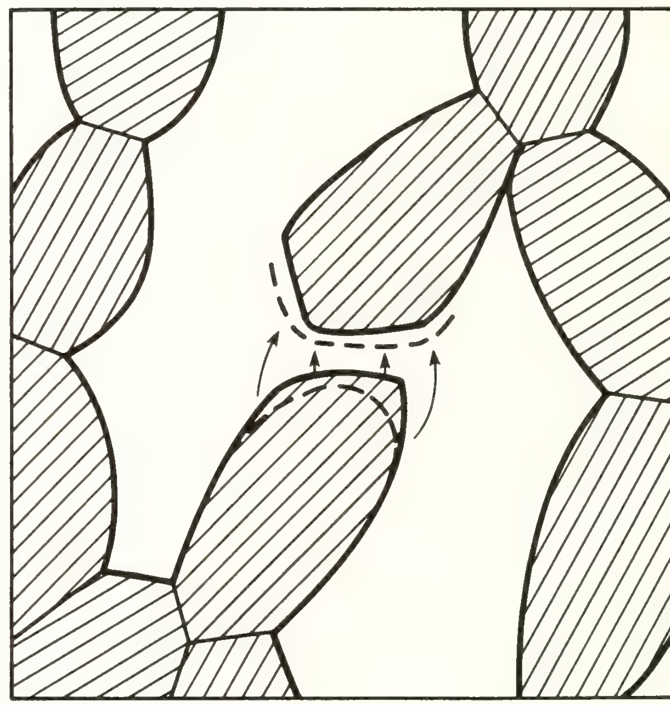

Figure 3.--Branch grain growth and decay after de Quervain (1973).

m is the mass concentration and the subscript refers to either the isotopic species or normal H_2O. Fick's second law for one dimensional flow is,

$$\frac{dm}{dt} = D_{eff} \frac{d^2m}{dz^2} . \qquad [4]$$

Thus, if there is no curvature in the mass concentration gradient, the change in the isotopic ratio is zero. The curvature is small in the center of a snow layer (fig. 1) when the temperature differential is held constant. However, there may be a considerable curvature near the upper and lower boundaries, particularly where the boundaries are impermeable. Then the vapor pressure changes from zero to that of ice in a short space.

This raises the problem of the microstructure. If snow strictly followed Yosida's hand to hand concept, a very large,

but finite change in the second derivative would occur only in the first layer of ice grains next to the boundaries. This effect might be observable with very careful work. Essentially, Yosida's model assigns a communication distance of one grain size to the transport of water vapor. The second possibility is that the average communication distance between grains is larger than one grain diameter.

Figure 4 shows schematically the isotopic ratios that would be expected after a period of time under the two models. Figure 5 shows the results of a series of measurements on snow samples held under a constant temperature difference for about one month. The first curve shows the transient effect from the initial high gradient at the boundaries that occurred when the temperature at the boundaries was first established. The change in isotopic ratio shows that the lowest layer lost mass to layers above it, and that the top layer lost mass to the plate that formed the upper boundary. After one month, the lower layers continued to lose mass while the upper layers gained mass. Furthermore, the knee in the lower part of the curve continued to move up. The experimental curves are most like figure 4C, which represents a communication distance of

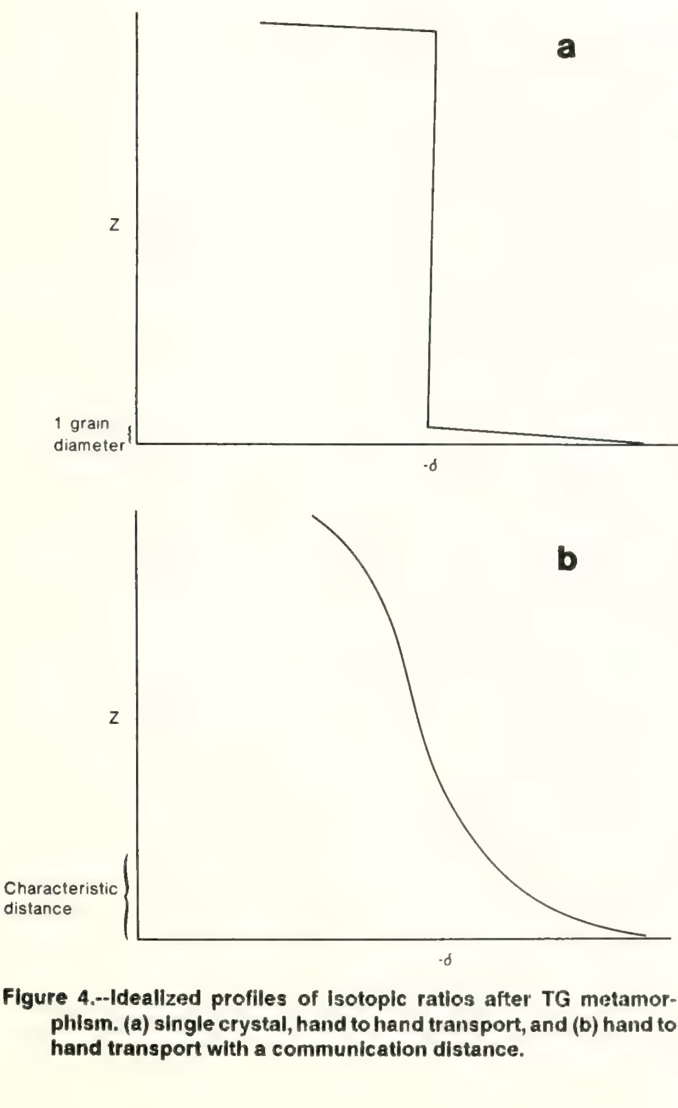

Figure 4.--Idealized profiles of isotopic ratios after TG metamorphism. (a) single crystal, hand to hand transport, and (b) hand to hand transport with a communication distance.

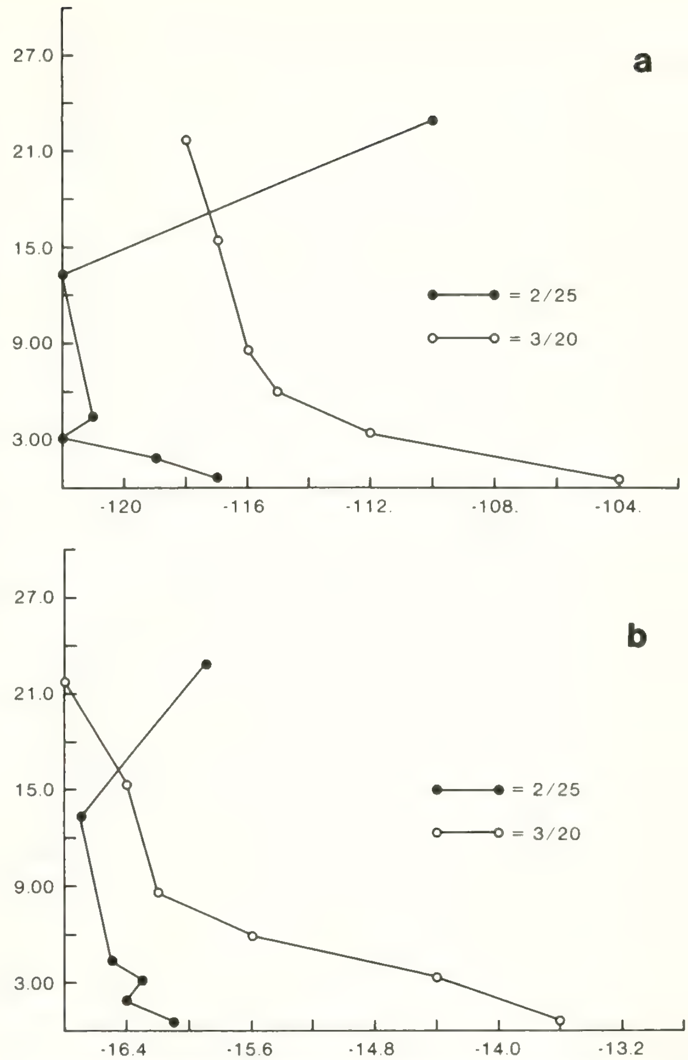

Figure 5.--Measured profiles of isotopic ratios. (a) HDO, and (b) $H_2{}^{18}O$.

more than one grain diameter. The grain diameter was of the order of 1 mm while figure 5 indicates that the mean communication distance is of the order of 10 mm, roughly 10 grains.

As equation [3] implies, the change of the isotopic ratios in a layer is directly related to the mass change of the layer. If mass is transported out of the layer, it loses more normal H_2O and the isotopic ratio increases. The opposite is true if it gains mass. Moser and Stichler (1980) present an experimental determination of the relationship between mass change and the change in the isotopic ratio. With this relationship and the measurements shown in figure 5, it is possible to calculate K_s. Both the HDO and the $H_2{}^{18}O$ results give

$$K_s = 2.3 \pm 0.2.$$

This result agrees with the maximum value calculated using the computer model of Christon et al. (in press).

These results are preliminary because (1) the accuracy of the results of Moser and Stichler (1980) has not been verified, and (2) the relationship between K_s and the microstructure

cannot be determined from this single experiment. However, the results show that the communication distance for vapor transport in snow is significantly larger than one grain diameter. Snow can therefore be treated as a continuum, K_S can be determined by measuring the changes in isotopic ratios and, in general, the mass change in a snow layer due to vapor transport can be determined from changes in the isotope ratios.

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Ecosystem Studies in the Subalpine Coniferous Forests of Wyoming

Dennis H. Knight[1]

Abstract--An overview is presented on recent ecosystem studies in the Medicine Bow National Forest and Yellowstone National Park. Most of the research has focused on lodgepole pine forests. Hydrology, leaf area development, decomposition, nutrient dynamics, soil chemistry, landscape ecology, and the effects of tree harvest, fire, and mountain pine beetles have been emphasized.

The subalpine elevations of Wyoming mountain ranges are characterized by a mosaic of meadows, lakes, and forests dominated by various mixtures of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and aspen (*Populus tremuloides* Michx.). As in other parts of the Rocky Mountains, vegetation patterns are determined by environmental factors associated with elevation, topographic position, soil characteristics, and the history of disturbances including fire, logging, and outbreaks of the mountain pine beetle (*Dendroctonous ponderosae* Hopk.). On the warmer and drier sites lodgepole pine appears to form a stable community that persists until fuel accumulation makes the next fire inevitable (Romme and Knight 1981, Despain 1983). Elsewhere spruce and fir are the climax species, sometimes developing in the understory of pioneer lodgepole pine or aspen forests but in other cases invading directly following a burn or some other disturbance (Stahelin 1943, Romme and Knight 1981).

For many years research on the subalpine forests of Wyoming was focused on species composition, classification, and succession. Such studies are essential for providing the understanding required for sound resource management, but many questions pertaining to nutrient cycling and water flows were not being addressed. Of course, research at the nearby Fraser Experimental Forest was providing good information on forest hydrology, but more remained to be done. Recognizing the importance of such research for management, my colleagues and I began to study the subalpine forests of Wyoming from an ecosystem perspective. In this paper I will provide an overview of some of our results thus far.

Most of our research thus far has focused on forests dominated by lodgepole pine and has been done at the stand level rather than at the scale of the watershed. Originally we had hoped to find a watershed in Wyoming that could be studied in the manner of the Fraser or Hubbard Brook watersheds, but during the search we concluded that our watersheds were so heterogeneous (in terms of vegetation, soils, and geologic substrate) that it would be difficult to evaluate biotic effects on water and nutrient fluxes -- one of our primary interests. Instead we selected homogeneous stands of a few hectares as our ecosystems. Such stands had the advantage of being closer to the scale of an actual timber sale than whole watersheds, and we hoped that they would provide the opportunity to examine more precisely the effects of vegetation structure on ecosystem processes. Studying stands instead of watersheds has its problems (Knight et al. 1985), but we felt they could be resolved in the relatively simple lodgepole pine forest. Most of the research has been done in the Medicine Bow National Forest, 50 km west of Laramie, but several studies were conducted in Yellowstone and Grand Teton National Parks as well.

Many individuals have helped in the development of our research, including colleagues at neighboring universities and with federal agencies, but the following individuals deserve special recognition: James F. Reynolds, Ned Fetcher, William H. Romme, Steven W. Running, Timothy J. Fahey, John A. Pearson, Joseph B. Yavitt, and Howard E. Haemmerle. These graduate students, listed in order of degree completion, worked long hours for little reward other than a chance to make a contribution to forest science. To a very large extent, it is their results that are highlighted in this overview. I am also especially grateful for the cooperation extended to us by the staff of the Medicine Bow National Forest. Our research has been funded by the National Science Foundation, Wyoming Water Research Center, University of Wyoming - National Park Service Research Center, Department of Interior (Office of Water Research and Technology), and the Department of Agriculture (U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station).

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Stand Hydrology

The streams draining Wyoming watersheds are important as sources of water for the semiarid basins below, as habitat for a popular sport fishery, and as sources of nutrients and sediments in downstream reservoirs. Everyone recognizes that streamflow is affected by watershed vegetation, but little was known about the hydrology of lodgepole pine forest at the scale of single stands. Reynolds and Knight (1973) calculated the importance of forest floor interception following summer rains, concluding that in most years winter snowfall is the only source of water adequate to cause water outflow beyond the rooting zone. Normally, only one pulse of outflow occurs each year. Moreover, the primary source of water for the lodgepole pine is from snowmelt, as most rains are completely intercepted by the canopy and forest floor.

The amount of spring outflow from a stand is dependent on the storage capacity for snowmelt water created by evapotranspiration (ET) during the previous year. Transpiration is known to be a substantial part of ET, but few data were available for stands of Rocky Mountain coniferous forest. Fetcher (1976) found that lodgepole pine stomatal resistance could be an important factor reducing transpiration towards the end of the growing season and that the degree of control was greater on drier sites. This information added to a growing body of information on the water relations of lodgepole pine (Swanson 1967, Owston, et al. 1972, Johnston 1975). With the assistance of better instruments for measuring transpiration in the field, Fahey (1979) and Running (1980a, 1980b) were able to accomplish a more detailed analysis of lodgepole pine stomatal behavior in relation to environmental conditions. Kaufmann (1984a, 1984b) conducted similar research on lodgepole pine, subalpine fir, and Engelmann spruce in Colorado.

Understanding stomatal physiology is important for hydrologic studies, but extrapolating to the whole tree or forest is difficult. Our initial attempt to resolve this problem for lodgepole pine was with the use of whole-tree potometers (Knight, et al. 1981). Entire 100-yr-old trees, up to 26 cm d.b.h., were cut and suspended in reservoirs of water for periods of several days. Careful monitoring suggested that the rate of water loss from the reservoir was a reasonable estimate of tree transpiration. Tree diameter and maximum observed 24-hour uptake were highly correlated, with the largest trees transpiring 40-44 L on clear days in early summer. Maximum observed hourly uptake for the larger trees was 2.5 to 3.5 L, with total nighttime uptake being about 12% of 24-hour uptake. On overcast days potometer uptake was reduced by 30-34%. Transpiration data for trees of different sizes were used to estimate a total clear-day transpiration from the forest of 3.3 mm. Interestingly, a very dense "dog-hair" stand, with 14,000 trees/ha, had about the same leaf area index (7) and transpiration rate as an adjacent more open stand with 2,000 trees/ha and a much higher basal area/ha.

Our most recent analysis of lodgepole pine forest hydrology involved more detailed measurements and a stand-level computer simulation model (Knight et al. 1985). Eight contrasting stands were compared over a 3-year period. Estimates of actual ET for the period from early spring to late fall ranged from 21 to 53 cm, which was 33-95% ($\bar{x}$ = 73%) of total annual precipitation. For all stands and years, transpiration accounted for 50-61% of ET, and 9-44% of the transpiration occurred during the spring drainage period while snow still covered the ground (vernal transpiration, VT). Estimated VT and outflow varied considerably among the stands (fig. 1), with VT accounting for 4-20% of the snow water. We estimated that outflow beyond the rooting zone occurred only during the snow melt period and accounted for 0-80% of the snow water.

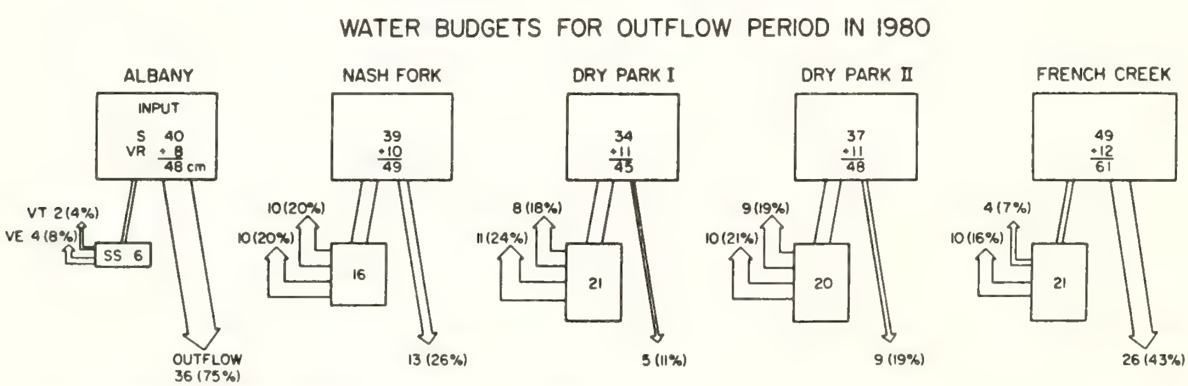

Figure 1.--Diagrams depicting the water budget of five contrasting stands of lodgepole pine forest during the 1980 outflow period (from the initiation of snow melt until the end of drainage). Units are cm-H_2O. See figure 2 for a generalized annual budget. The amount added to the value for the maximum snow water equivalent (S) is vernal rainfall (VR), i.e., rainfall that occurred during the snow melt period. The smaller boxes represent soil storage (SS) and are full at the end of the outflow period. Percentages in parentheses indicate the proportion of S + VR flowing via outflow, vernal transpiration (VT), and vernal interception (VE) during the outflow period (as estimated with a computer simulation model). From Knight et al. (1985); reprinted with permission of the Ecological Society of America.

Outflow could be reduced to zero under conditions of high VT, high soil storage capacity, high LAI, relatively slow snowmelt, and average or below snow water equivalent. The hydrology of deciduous aspen forests should be considerably different because they lack the potential for VT, but we have not yet studied this kind of vegetation in detail. Figure 2 contrasts the hydrology of a typical stand of Wyoming lodgepole pine to a stand of Douglas fir in Oregon.

In sum, our results are helping to quantify the generally accepted concept that stands differing in structure and environmental conditions experience different rates of water outflow at different times during the snow melt season, contributing differentially to stream hydrograph shape.

Forest Leaf Area

Leaf area, whether evergreen or deciduous, is an important determinant of transpiration rate as well as photosynthesis and aerosol impaction, but until recently little information has been available on this important forest parameter. Usually leaf area is expressed as leaf area index (LAI, m^2 leaf surface area/m^2 ground surface area). Deciduous forest LAI is often calculated for a single leaf surface while all surfaces are commonly included for the LAI of coniferous forests.

LAI is a stand feature that varies with habitat type and is, of course, affected by silvicultural practices. Utilizing our computer simulation model, which includes LAI as a key variable, we observed that increases in water outflow following any kind of disturbance is proportional to the decrease in leaf area (Knight et al. 1985). Removal of leaf area appears to be more important than reductions in tree density or basal area (Knight et al. 1981).

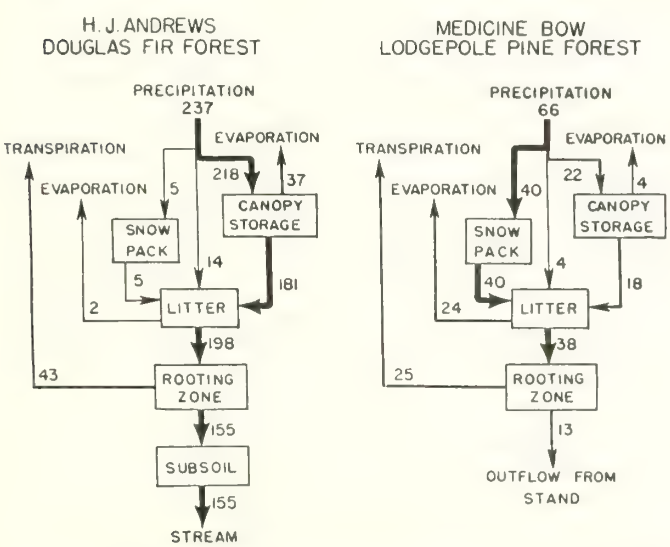

Figure 2.--Generalized annual hydrologic budgets for the H. J. Andrews Douglas fir forest in Oregon and a typical stand of lodgepole pine forest in the Medicine Bow Mountains. Numbers are cm-H_2O per year. The figure for Douglas fir is redrawn from Sollins, et al. (1980), and is used with permission of the Ecological Society of America.

These observations led to a study designed to determine how LAI changes with site quality and forest age (Haemmerle et al., submitted). Forty-three stands in the Medicine Bow Mountains were divided into two series, one in which lodgepole pine appeared to be the long-term dominant and another where subalpine fir was common. A maximum LAI of 16 was calculated for a stand from the pine series, while 39 was the maximum LAI for the fir series. Maximum leaf area in the pine and fir series is reached in 125-200+ and 200-300+ years, respectively, with more time required as site quality declines. Differences in maximum leaf area and the timing of this maximum probably are caused by tree establishment patterns, physiological differences among species, and site water balance. The relationship of LAI to important ecosystem processes and the fact that LAI is now being estimated more easily (Pearson et al. 1984, Haemmerle et al., submitted), even from satellites (Running 1986), suggests that it can and should be used more frequently in forest management decisions.

Nutrient Conservation and Outflow

Water passing through the soil profile, beyond the root zone, carries dissolved nutrients which are losses to the terrestrial ecosystem but inputs to ground and surface water systems. Considering that a large proportion of litter decomposition occurs during the winter under snow (Fahey 1983), and that the only pulse of water adequate for leaching occurs in the early spring before vigorous tree growth, we wondered if each year there is a "spring flush" of nutrients beyond the rooting zone that tends to maintain the soils in a nutrient-deficient state. Nutrient outflow/atmospheric input ratios were estimated, with the results being consistently < 1.0 for N; consistently > 1.0 for Ca, Na, and Mg; and ranging from 0.3 to 2.0 for P and 0.2 to 3.3 for K. These results suggest that N usually is accumulating in lodgepole pine forest ecosystems, even during years of heavy snowpack and and large volumes of outflow, probably due to microbial or vascular plant uptake; and that P and K may accumulate on some sites. Weathering, another input for elements other than N, could not be estimated for our analysis and, therefore, the ratios for these elements are difficult to interpret.

Simple estimates of nutrient inputs and outputs are useful for ecosystem studies, but they ignore the processes involved. To improve our understanding, several studies were initiated on litter decomposition, nutrient retention, and other factors affecting soil water chemistry. The nutrient dynamics of aboveground detritus were studied by Fahey (1983), who found that decaying leaves and wood actually increase in N, P, and Ca during some stages of decomposition. For example, nitrogen content of decaying boles doubled between 30 and 55 years following tree death before beginning a slow decline after the C/N ratio of the wood drops to a critical level (Fahey and Knight 1986). This and other research suggests that N is one of several limiting factors for the lodgepole pine ecosystem, whether for the microbes or vascular plants, and that

decaying logs may be an important source of N for sustained site productivity. Dead wood resulting from the last disturbance, usually a fire in the case of our stands, was a major nutrient storage compartment, sometimes exceeding other forest floor components by several-fold in 80-100 yr old stands. Silvicultural practices that lead to significant reductions in the amount of woody detritus may be detrimental to long-term site productivity.

Ecologists and managers commonly focus on aboveground biomass, but Pearson et al. (1983) estimated the amount of root biomass as well in Wyoming lodgepole pine forest. They found that the average proportions of biomass in boles, branches, foliage, woody roots, and fine roots were 61, 7, 6, 20, and 6%, respectively, with root/shoot ratios ranging from 0.27 to 0.50. The highest ratios were in the more dense stands. Interestingly, the proportion of biomass in fine roots was about equal to the proportion in leaves. Ninety percent of the root biomass was within 40 cm of the surface in lodgepole pine forests, though tap roots were observed down to a depth of 2 m or more. Whereas Fahey (1983) studied detrital decomposition above ground, Yavitt and Fahey (1982) estimated rates of root decomposition. Despite being in closer proximity to soil moisture and soil microbes, woody roots appeared to decompose no more rapidly than aboveground boles of comparable size. Both may last a century or more. Complete mineralization of leaves requires 12-22 years, depending on site conditions (Fahey 1983).

As decomposition occurs, the soil solution is enriched in a variety of ions that could be leached beyond the rooting zone. For a time we thought that N was retained within the forest floor, due to the extremely low concentrations of NH_4^+ and NO_3^- in forest floor leachate, but subsequent studies revealed that the major transfer of N from detritus to mineral soils occurred in soluble organic compounds (Yavitt and Fahey 1985, Fahey et al. 1985, Yavitt and Fahey 1986). However, despite relatively high N fluxes to the mineral soil in organic compounds, little N of any kind could be detected in water samples collected near the bottom of the rooting zone. Observing that finer textured soils had lower N concentrations than more coarse soils, Fahey and Yavitt hypothesized that adsorption onto colloids was an important abiotic mechanism for N immobilization.

Annual N inputs from fixation and precipitation appear to be very low in lodgepole pine forests (fig. 3), as are decomposition rates, and consequently N could be an important limiting factor along with the short, cool, sometimes dry growing season (Fahey and Knight 1986). Fahey et al. (1985) found that about 90% of the N pool was in the soil organic matter, with 6% and 4% in aboveground detritus and living biomass, respectively. They hypothesized that some of the N available for microbial growth in the detritus was translocated to the forest floor from the mineral soil by fungal mycelia, and that a portion of the N required for tree growth was obtained by translocation from senescing leaves to twigs (as reported for other conifers, Gosz 1980). Of course, the slowly decomposing forest floor and soil organic matter are important sources as

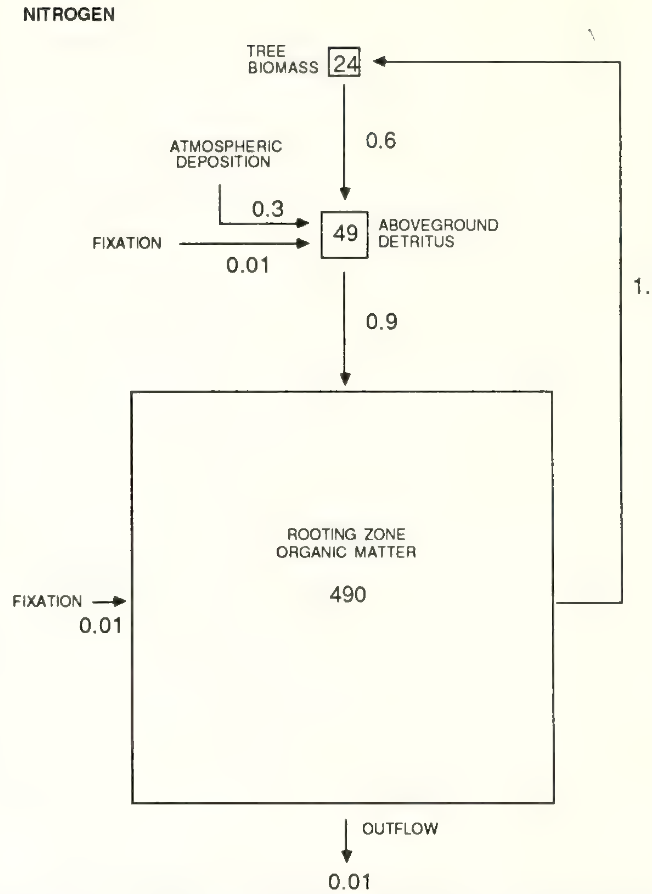

Figure 3.--Generalized annual nitrogen budget for a typical 100-yr-old stand of lodgepole pine forest in the Medicine Bow Mountains, drawn from data presented in Fahey et al. (1985). Numbers in boxes and by arrows are g/m^2 and g/m^2/yr, respectively. Much of the N in the rooting zone compartment is in organic matter that apparently is not readily decomposable, as the mean tissue N concentration of the foliage is low (0.7%) compared to other coniferous species. Note (1) that N inputs to the ecosystem are larger than N losses, suggesting that N is accumulating, probably due to being a limiting factor for the biota; and (2) that the tree uptake estimate is larger than the sum of the input estimates to the rooting zone, which suggests that the soil N pool is gradually being depleted in this aggrading forest. Replenishment of the soil N pool may occur as the forest ages further (Fahey and Knight 1986).

well. David Coleman and his associates, from the University of Georgia and Colorado State University, are studying the interspecific microbial interactions affecting decomposition in one of our Medicine Bow study areas.

Other chemical fluxes have been studied, with the observation that the slightly acidic rainfall (mean pH = 4.6) is commonly neutralized to pH 5.2, probably by basic, microscopic aerosols (dry deposition) from upwind deserts (Fahey and Knight 1986). The neutralizing capacity of forest soils in the Medicine Bow Mountains is substantial due to the accumulation of such aerosols, an observation relevant to concerns being expressed about acid precipitation (Reiners et al., in preparation). Potential nutrient loss via leaching is accelerated by acidic soil water (Fahey et al. 1985), whether natural

or anthropogenic, but biotic sources of hydrogen ions appear to be more important than precipitation at the present time (Fahey and Knight 1986).

Effects of Disturbances and Succession

A widespread technique for studying ecosystems is to monitor changes in energy, water, and nutrient fluxes following disturbances to the biota. Sometimes natural disturbances such as fires or insect outbreaks can be used, but more controlled "treatment" perturbations and computer simulation "experiments" are other options. All three have been used in our research. Most have been done at the scale of a single stand covering several hectares, but others have focused on landscapes.

Our initial studies at the stand level involved simulation of a clearcut using the hydrologic model H2OTRANS (Running 1984, Knight et al. 1985). Computer simulations suggested that the increase in water outflow is, to a large extent, dependent on the amount of leaf area removed. Of course, timber harvesting is a standard tool for increasing streamflow.

Another approach was tree thinning. A 20 x 40 m plot in our Fox Park stand was thinned by tree girdling and another comparable plot was clearcut. A control stand was located within 40 m on the same soil type. The experiment provided an opportunity to examine the effects of removing two levels of leaf area and killing different numbers of trees. The thinning treatment was designed to duplicate, to the extent possible, the effects of a mountain pine beetle outbreak and included painting the exposed sapwood with spores of blue stain fungi -- the type of fungi that are also introduced by the beetles and which are believed to account for the rapid demise of the shoots (we observed that trees that are only girdled may live for 5 years or more). The clearcut and thinning treatments were applied in 1982, with the hypothesis that increases in water and nutrient outflow would be proportional to the amount of leaf area removed (clearcut > thinned > control).

The results for nutrient outflow were not what we anticipated (Knight et al, in preparation). Killing 60% of the trees by girdling, mostly the larger trees (as often occurs following a bark beetle infestation), had very little if any effect on the outflow of N, K, and Ca. In contrast, killing all of the trees via clearcutting increased N outflow by 40 times, K outflow by 3 times, and Ca outflow by 3 times. A similar pattern was observed for the concentrations of nitrate and total nitrogen in soil solutions. Hardly any concentration differences were observed when comparing the control and girdled stands, but nitrate concentrations were commonly > 100 times higher in the clearcut stand.

These results are interesting from at least two perspectives. First, we wondered if the high C/N ratios of the forest floor might negate the importance of N uptake by trees for limiting N outflow beyond the rooting zone. This proved not to be the case, as an abundance of leachable nitrate was observed in the clearcut stand. Apparently nitrification bacteria were able to produce more nitrate when competition for N by the trees was eliminated. While somewhat warmer soil surface temperatures would have existed in the clearcut stand, it seems doubtful that this difference alone could produce the great differences observed.

Secondly, the results of our experiment imply that the surviving trees in a thinned stand are able to absorb the nutrients formerly being used by the "dead trees." Our first inclination was to think that the roots of adjacent trees are so intermingled that as the roots of one tree die, the roots of nearby trees grow to fill any root gaps that are created. This may be the case, but other explanations are possible. For example, the root systems of adjacent trees are commonly grafted in pine forests (Graham and Bormann 1966). Is it possible that the root system of the surviving tree could somehow sustain through grafts, or mycorrhizal connections, the root system of the girdled tree? Do root systems become dysfunctional at the same time as the shoot dies? Are root gaps created at the same time as canopy gaps? Research on these questions is currently underway in one of our lodgepole pine stands. The results should clarify root growth dynamics following disturbances and the importance of root growth for regulating nutrient outflow.

Ecosystem development or change following disturbance is a topic of widespread interest among ecologists. The comparison of stands of different ages but on similar sites is a common approach for addressing this topic, but Pearson et al. (in press) attempted to use the tree ring record in the living and dead trees to examine biomass and nutrient accumulation during the history of the relatively simple lodgepole pine forest in our area. Changes in dead wood, forest floor, and live tree biomass (including roots) were estimated separately. Maximum total biomass accumulation rates of 2.5-3.2 metric tons/ha/yr were reached 40-60 years after fire in even-aged stands, but an uneven-aged stand developing on a former meadow did not achieve a maximum accumulation rate (1.5 tons/ha/yr) until after 80 years. Biomass increment occurred primarily in the living vegetation compartment throughout stand development, except for brief episodes of increment in the dead wood compartment associated with the mortality of large trees. Maximum forest floor biomass increment generally was about 25% as high as maximum living biomass increment. It is difficult to say when biomass accumulation rates will approach zero, i.e., when net primary productivity is balanced by heterotrophic respiration, and indeed the stand may burn before this happens. With sufficient time fuels develop to the point where fires become inevitable, whether the ignition source is lightning or humans.

With regard to nutrient accumulation, Pearson et al. (in press) suggest that the forest floor is the major biomass compartment accounting for the immobilization of N, P, Ca, and Mg, at least during the first 40-80 years of stand development. Living biomass appears to be next most important, especially after 60-80 years, and accounted for most K accumulation throughout stand development. The importance of dead wood is suggested as well, especially while the stand is

about 20-80 years old and when dead wood from the previous forest is still an active site for nutrient immobilization. Nutrient increment rates remained positive even in the oldest stand (about 200 years old).

Mountain Pine Beetle Ecology

As noted, outbreaks of mountain pine beetle are a natural disturbance in many western coniferous forests. A common notion is that older stands become more susceptible to the bark beetles, which create canopy gaps that release the growth of smaller suppressed trees, thereby maintaining a higher level of primary productivity than would occur otherwise. The interaction brings to mind cybernetic systems with feedbacks that control certain processes, in this case photosynthesis. Romme et al. (1986) examined this question in Yellowstone and Grand Teton National Parks, observing that indeed annual wood production per hectare usually returned to pre-outbreak levels or exceeded them within 10-15 years. However, their estimates of annual wood production over the last 70-80 years indicated that the beetle outbreak introduced more variation in productivity than would have existed in their absence. They concluded that the mountain pine beetle do not function as cybernetic regulators, at least in the strict sense. Nevertheless, because of the rapid recovery of annual wood production, they suggested that the effects of the beetles could be considered generally benign or even beneficial in some situations (e.g., increased understory growth may favor certain animals).

Could outbreaks of the mountain pine beetle affect the probability of crown fires? In another study in Yellowstone National Park, Romme et al. (in preparation) concluded that, while flammability may increase during the first year or two after an infestation because of dead leaves still on the trees, the risk of destructive fire during years 2-20 may be lower because (1) the leaves and many twigs fall off, reducing fuel continuity, and (2) the proportionate increase in forest floor fine fuels is small by the time the forest is old enough to be susceptible to a beetle outbreak. Accelerated growth in understory trees may increase fuel continuity and fire risk after 20 years.

Other studies have been done on forest fire ecology in Wyoming (Loope and Gruell 1973, Despain and Sellers 1977, Bartos and Mueggler 1979, Romme and Knight 1981, Romme 1982, Despain 1983, 1985; Knight 1987; Stottlemeyer 1987). Some of these studies focus more on community succession than on energy-, water-, and nutrient-related processes, but all aspects of disturbance ecology are relevant to understanding ecosystems.

Landscape Ecology

In recent years ecologists have become more conscious of the scale at which their research is being done. Some focus on leaves or other appendages; others focus on whole organisms, and still others on communities, i.e., rather arbitrarily defined assemblages of organisms. As usually addressed, the ecosystem scale is comparable to the community scale. The study of ecosystems always involves addressing community and individual organism characteristics to some degree but, as should be apparent in this paper, the focus is more on energy, water, and nutrient fluxes rather than on species composition. Community and ecosystem research usually involves the study of relatively homogeneous stands that are more or less a few hectares in size, or processes that are important at that scale. At least two other scales can be studied as well, i.e., the landscape scale consisting of a mosaic of communities over an area of a square kilometer or larger (more or less), and the biospheric scale where data are collected for the whole earth.

Landscape studies have great relevance to ecosystem research, and vice versa. Using aerial photos, the tree ring record, and computer simulation techniques, Romme (1982) was able to date and map the occurrence and areal extent of fires during the last few centuries in a 73 km^2 tract of subalpine forest and meadows in Yellowstone National Park. He demonstrated how the proportion of this landscape in young, middle, and older stages of succession changed considerably through time (fig. 4). Romme is now working with Don Despain, Park Research Biologist, to determine if larger portions of the Park are in what has been referred to as a "shifting mosaic steady state" (Bormann and Likens 1979). Romme could find no evidence that fire suppression had affected the subalpine forest mosaic that he studied, primarily because large fires have occurred there at long intervals of 300-400 years and fuel accumulation since Park establishment generally has not been sufficient to support large fires. In a subsequent paper, Romme and Knight (1982) speculate on the implications of shifting mosaics for water and nutrient out-

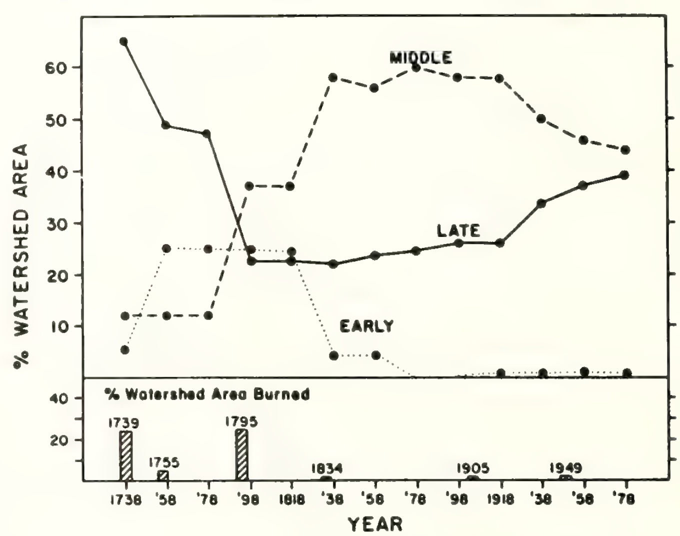

Figure 4.--Percent of a 73-km^2 area in Yellowstone National Park covered by forests in early, middle, and late stages of succession, and the percent of the area burned in a series of fires from 1738 to 1978. The shift occurring in the predominant successional stages suggests that the area is not in a "shifting mosaic steady state." From Romme and Knight (1982); reprinted with permission of the American Institute of Biological Sciences.

flow, lake productivity, song birds, and elk. Knight (1987) reviewed the effects of coniferous forest mosaics on flammability and the spread of parasites.

The landscape scale seems highly relevant to the management of National Forests and wilderness areas, since roads, campgrounds, timber harvesting, habitat improvements, and fire suppression are creating new mosaics. In some areas forest fragmentation is occurring (Harris 1984), while elsewhere there is the potential of landscape homogenization due to fire suppression (Habeck 1985). Landscape architects have been employed to design aesthetically pleasing landscapes, but what is the ecological impact of different landscape designs? Is there an ecological rationale for prescribing one vegetation mosaic over another? Optimal mosaics apparently can be designed for water yield (Leaf 1975) and for certain wildlife species (Thomas et al. 1976, Harris 1984), but less is known about the effect of the mosaic on, for example, biotic diversity, maintaining a certain level of primary or secondary productivity, the spread of fire or insect epidemics, and nutrient fluxes that could affect site productivity or streamwater quality. Large National Forests in the Rocky Mountain states provide excellent locations for such research because the landscape mosaics are being manipulated now and will be for many years to come.

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Partial Cutting in MPB-Susceptible Pine Stands: Will It Work and for How Long?

J. M. Schmid[1]

Abstract--Partial cutting in mountain pine beetle-susceptible stands shows promise in reducing tree mortality. Mortality appears to be least in the lower growing stock levels. RMYLD predicts GSL 80 and GSL 120 stands will remain unsusceptible for 40 to 50 years and < 20 years, respectively. The Berryman model predicts GSL 80 and GSL 120 stands will be highly and extremely susceptible within 10 years after cutting.

Silvicultural treatment of lodgepole and ponderosa pine stands shows promise in reducing tree mortality caused by the mountain pine beetle. Initial treatments removed the most susceptible trees (Cole and Cahill 1976)-- either by clearcutting or cutting the larger diameter trees ($\geq$ 12 inches d.b.h.). When enough trees $\geq$ 12 inches were not available, then progressively smaller trees--trees $\geq$ 10 inches or $\geq$ 8 inches--were cut, depending on how much additional basal area or volume was to be cut. These treatments reduced MPB losses, because they removed all suitable host material. Such partial cuts may yield the most commercially desirable product, but generally are not totally satisfactory because they leave a less desirably stocked stand of poorer quality with uneven spacing, while removing the dominant, more rapidly growing trees.

To avoid these detrimental aspects, more recent cuttings have emphasized leaving regularly spaced, larger diameter trees of better form and well- developed crowns. Current studies are leaving growing stock levels (GSL) ranging from 40 to 120. In the Black Hills, ponderosa pine stands are being cut to GSLs from 60 to 100 on sites with SI < 65, and GSLs 80 to 120 on sites with SI $\geq$ 65 (fig. 1). In lodgepole stands in Colorado and Wyoming, GSLs of 40, 80, and 120 are being installed. In Front Range ponderosa pine, GSLs of 40, 60, and 80 will be tested where suitable conditions can be found.

For all of these cutting levels, two questions are being asked: (1) will they reduce MPB-caused mortality, and (2) how long will the treatment be effective? Evidence gradually forthcoming indicates that partial cutting will reduce MPB mortality, and the MPB mortality is least at the lowest GSL and greatest at the higher GSL (McGregor et al. 1987). Preliminary results in Wyoming indicated little mortality in a 100-leave tree cut (Cole et al. 1983). However, mortality should have been low in this test, because the leave trees were marginally susceptible (8 inches) and stand density was extremely low (GSL 40). Subsequent results from Oregon indicated the 18- by 18-foot or 21- by 21-foot spacings (lower GSLs) have less mortality than the 12- by 12-foot or 15- by 15-foot spacings (higher GSLs). GSL 80 and 100 partial thinnings in Montana showed greatly reduced losses (McGregor et al. 1987). GSL 120 treatments in the same area suffered losses similar to untreated stands, but spacing in them was not always uniform. These early results suggest partial cutting will reduce MPB losses, but they have spawned the further question of what level of cutting will yield minimal MPB losses and maximum timber production.

The second question--how long will partial cuts remain effective-- currently cannot be answered, except through model projections. Preliminary unpublished data from Oregon suggest at least 15 years is possible for stands with a mean diameter < 8 inches. For stands greater than 10 inches, the question remains unanswered, although studies in progress should ultimately answer this question.

Hypothetical answers can be derived by projecting development of recently cut stands through two models--RMYLD (Edminster 1978) and the Berryman model (Berryman 1978). If stands are assumed to become susceptible when their basal area (BA) reaches 150 square feet per acre (Sartwell and Stevens 1975), then RMYLD estimates stands cut to GSL 60 remain generally unsusceptible for 60 to 80 years, GSL 80 for 40 to 50 years, GSL 100 for 25 to 40 years, and GSL 120 for < 20 years (table 1).

One legitimate criticism of these projections is the precision of the assumption of susceptibility at BA 150. Although stands may be just as susceptible at BA 140 or 160, BA 150 is useful in comparing different GSLs until the relationship is more precisely defined.

Stand projections beyond 30 to 50 years seem irrelevant in view of Forest Service policy of achieving stands with a mean diameter of 12 inches at rotation ages of 100 to 120 years.

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Considering the stands used in these projections already have attained these objectives, concern for the duration of effectiveness seems questionable. However, full regulation of the commercial stands may not be achieved for another rotation because of the imbalance of age classes, so partial cutting of and concern for larger diameter stands is relevant.

The Berryman model rates stands as low, high, or extreme risk based on (1) the percent of the basal area with phloem thickness > 0.1 inch and stand resistance, where stand resistance equals the periodic growth ratio (PGR) divided by the stand hazard rating for trees older than 60 years. For computation purposes in this paper, data were taken from partially cut stands currently being studied. The stands are 100% ponderosa or lodgepole pine, and the phloem thickness is assumed to be > 0.1 inch on nearly 100% of the trees after 10 years. PGRs (PGR = radial growth last 5 years divided by radial growth for the 5-year period prior to the last 5 years) equal to 1.0 and 1.2 are from unpublished thinned stand data. Stand hazard rating (SHR) equals crown competition factor (CCF) times percent of the stand in pine (PLPP) divided by 100 (SHR = CCF x PLPP/100).

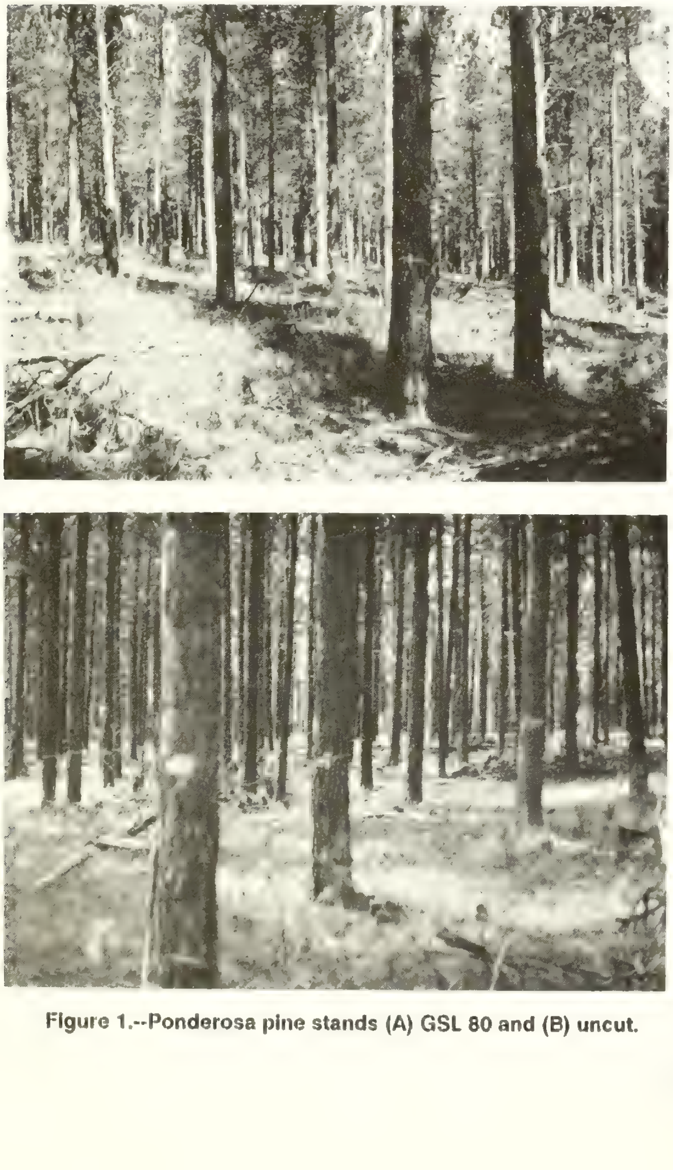

Figure 1.--Ponderosa pine stands (A) GSL 80 and (B) uncut.

Table 1.--Time and stand conditions when partially cut stands reach a basal area of 150 square feet per acre as projected by RMYLD.

Area/growing stock level	Conditions after thinning		Conditions when BA ≥ 150 (RMYLD)	
	mean D	BA	Time	mean D
	inches	feet/acre	years	inches
Brownsville (PP)				
60	12.4	60.5	76	19.5
80	11.5	80.8	51	15.7
100	12.8	100.7	37	15.6
Hinman (LP)				
80	12.8	79.8	40	17.6
100	12.7	101.2	27	15.5
120	10.9	118.1	13	12.3
Brush Creek (LP)				
40	9.8	40.0	90	19.6
60	12.0	60.7	62	19.9
80	10.0	81.3	40	13.6
120	8.9	119.7	16	10.2

The Berryman model indicates that GSLs 100 and 120 are highly or extremely susceptible 10 years after cutting (table 2), regardless of the PGR. GSLs 40 and 60 generally rate low in susceptibility for 20 years when PGR = 1.2 but tend toward high susceptibility when PGR = 1.0. For 10 or so years after cutting, PGR may approach 1.2 but within 10 to 20 years, PGR declines toward 1.0. Thus, PGR is significant only for the short-term, because it tends to stabilize. Later PGR will decrease as competition begins. The most important factor in the model appears to be the crown competition factor, which is mainly a reflection of tree diameter and growth.

The Berryman model and RMYLD projections both indicate that higher GSLs (100 to 120) become susceptible before the lower GSLs (40 to 60). However, the Berryman model

Table 2.--Time for partially cut stands to become susceptible[1] according to the Berryman model.

Area/growing stock level	Risk rating: PGR = 1.0		Risk rating: PGR = 1.2	
	10 years	20 years	10 years	20 years
Brownsville (PP)				
60	Low	Low	Low	Low
80	High	Extreme	High	High
100	Extreme	Extreme	High	High
Hinman (LP)				
80	High	High	Low	High
100	High	Extreme	High	High
120	Extreme	Extreme	Extreme	Extreme
Brush Creek (LP)				
40	Low	Low	Low	Low
60	Low	High	Low	Low
80	High	Extreme	High	High
120	Extreme	Extreme	Extreme	Extreme

1Low = low susceptibility; High = high susceptibility; Extreme = extreme susceptibility.

seems to project stand becoming susceptible earlier than RMYLD does. Eventually, data from these silvicultural studies will validate which model most accurately predicts the duration of effectiveness, and may redefine our susceptibility levels.

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The Measurement of Changes in a Colorado Subalpine Ecosystem Resulting from Alternative Recreation Camping Behaviors

Deborah J. Overton and Glenn E. Haas[1]

A principle of wilderness management is to use the "minimum tool" necessary to control recreation use (Hendee, et al. 1978). This principle is based on the public perception and desire to have opportunities in wilderness that are characterized by lack of restrictions, freedom, spontaneity and escape from daily work lifestyles. Hence, federal land managers often prefer to employ less regulative actions; those which indirectly alter human behavior (e.g., information or education) as opposed to those which directly regulate human behavior (e.g., party size or designated campsites).

In favor of the "minimum tool" management approach, federal land agencies have begun a large scale information and education campaign entitled, "Minimum Impact Camping". The intent is to educate recreationists as to how they can minimally impact natural areas. The hope is that (1) increased awareness and knowledge will lead to (2) altered or appropriate human behavior which will lead to (3) minimal alteration of ecosystem processes and quality of appearance.

Focus of the Study

It is generally assumed that the amount of impact in a subalpine ecosystem will be less if recreationists follow prescribed minimum impact camping behaviors (MICB) rather than traditional impact camping behaviors (TICB). In this study: MICB is defined as camping without a campfire (stove only); where such living activities as cooking, eating and relaxing are dispersed away from the tent; human artifacts (trash, log or rock seats) are not apparent; and soft soled shoes are worn in camp. TICB is defined as camping with a campfire; where such living activities as cooking, eating and relaxing are concentrated around the campfire; human artifacts are likely (rock fire ring, woodpile, rock or log seats, trash in firepit); and camp shoe type is of individual choice. Light use campsites are defined as having no previous recreation use through 9 nights use per year.

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The study compares the effect of two alternative camping behaviors, MICB and TICB, to establish the functional relationship between: (1) amount of use and amount of impact, (2) human behavior and system modification at light use subalpine campsites. More specifically, the hypotheses are:

1. The amount of impact is greater for the TICB treatment than for the MICB treatment.
2. There is no treatment time interaction for each of the weekly treatment applications.

The research design incorporates MICB and TICB treatments administered over a 2 year monitoring period during the summers of 1986 and 1987. This is a progress report summarizing the results of the first year of the study, an assessment of the changes that occurred throughout the 9 treatments and how these changes relate to the type of recreational behavior at each site.

Related Research

Detailed studies of wilderness campsites are few. Most impact studies have centered on developed campsites accessible by car receiving much heavier use. Wilderness campsite condition studies have been conducted in northern Minnesota (Merriam, et al 1973; Frissell and Duncan 1965), the eastern United States (Leonard, et al 1983; Bratton 1978), Oregon (Cole 1982), Idaho (Coombs 1976), and Montana (Fichtler 1980). Of these studies, only Cole (1982), Fichtler (1980) and Coombs (1976) begin to quantify low use data.

Previous studies of wilderness campsite deterioration concentrated on documenting vegetation cover losses through mechanical damage; i.e., trampling studies (Emanuelsson 1979; Liddle 1975; Burden and Randerson 1972) and soil deterioration at campsites (Leonard and Plumley 1979; Legg and Schneider 1977). Live tree damage, mutilations and scarring was reported by Cole (1982). Seedling loss was reported by Cole (1982), Coombs (1976) and Fichtler (1980). Cole (1982) concluded that prevention of seedling elimination may be most critical due to loss of future overstory.

Conclusions about the relationship between use and impact vary. Frissell and Duncan (1965), working in the BWCA, found no relationship between amount of use and either vegetation loss or bare ground. Merriam, et. al. (1973), also working in the same area, found a more consistent relationship between vegetation loss and amount of impact when sites were stratified by vegetation type. Cole (1982) reported that the response of variables as use increases is poorly understood, especially in the light use portion of the impact/amount of use spectrum.

A partial explanation for the difference in results may lie in the method of analysis employed by individual researchers. The functional relationship between impact and use is hyperbolic rather than linear; i.e., the rate of impact increase decreases as use increases (Cole 1982). Also, the amount of impact is not the same for every variable. Typical research results relating campsite impact variables and amount of use show an exponential increase in impact levels from light use, less than 5 nights per year to moderate use, estimated at 10 to 20 nights per year (Cole 1982). Coombs (1976) found the most pronounced differences among sites (light, moderate, and heavy use) to occur between light use and moderate use sites.

Study Area

The Comanche Peak Wilderness was selected for study because of its proximity to Fort Collins, as a primary source of treatment volunteers; location where recreation and other social uses could be controlled; visitor use patterns similar to other eastern slope wilderness areas; and the representativeness of the are to the many glaciated, mountainous wilderness areas in Colorado and the central Rocky Mountain region.

The Comanche Peak Wilderness is located along the north and northeast boundary of Rocky Mountain National Park in the Mummy Range, encompassing 27,316 ha of the Roosevelt National Forest in north central Colorado. The terrain, in general, consists of a high rolling plateau at approximately 3350 meters in elevation, reaching 3810 meters at Comanche Peak.

Study Site Selection Criteria

Subalpine lakes are a primary destination for most visitors to the Comanche Peak Wilderness. Brown's Lake, at 3180 meters elevation, typically receives 30 visitor days of use each weekend during the summer (personal observation). Unauthorized public use of study campsites was controlled for by locating sites one mile away from Brown's Lake, a major destination point/water supply source, and by locating sites off the main travel route, the Brown's Lake Trail. Further, study sites were unobtrusively posted and roped off in the event that a site was discovered by the public.

Environmental differences were minimized by selecting sites located within the same drainage, on a south facing aspect on soils derived from granitic bedrock. All sites are within the *Descampsia caespitosa* association. This permits the effects of alternative camping behavior to be measured more precisely. Control sites are located in the vicinity of each treatment plot in order to determine measures of natural variation. All measurements on control plots are identical to measurements on treatment plots.

Field Methodology

In order to estimate the amount of change and rate of change that occurs on each treatment site, it is important to begin weekly measurements from a permanent starting point. Therefore, the data collection procedure utilizes the point method, where the quadrat is reduced to an infinitely small point and permanent starting/ending points are located between baselines. In practice, a point frame is held perpendicular to the ground and sharp tipped metal pins are lowered until intercepting vegetation, litter or bare ground. Each plot is measured systematically by extending 11 line transects from the permanent baseline points. Basal point measurements are taken every 10 cm along each transect. These measurements yield unbiased estimates of cover, frequency and density.

The following categories of vegetation cover variables are measured weekly for each treatment and control plot: forb, grass, grass like, shrub, tree, ground cover (mosses and lichens), litter, bare ground and rock. Human artifact development, i.e., fire ring, ash, woodpiles, trash, rock or log furniture, and loss of downed wood, are measured on treatment sites.

A count procedure is used to measure tree seedlings, live tree mutilations/scarring, loss of downed wood and human artifact development. All human artifacts are left in place from treatment to treatment in order to monitor manipulative activity.

Each treatment site is partitioned according to vegetation/visual impact zones developed as a result of alternative behavioral patterns. Five zones are delineated: vegetation erect (no recreation activity); vegetation flattened and green (tent site); vegetation flattened and brown (concentrated activity); litter; bare ground. Post test measures of soil physical properties (bulk density, percent moisture) and biomass within each impact zone provide additional estimates of covariance within and between treatments.

Volunteer Selection

Potential camping volunteers are interviewed and assigned to either the MICB or TICB group, depending upon their level of camping behavior knowledge and experience. Three teams of 2 people comprise each group. Participants are escorted in separate groups to their respective campsites. Both groups are informed that they are participants in an elk human interaction impact study. Participants are requested to confine their living activities (cooking, eating, relaxing) to the study site in the evening hours in order to equalize time spent at each campsite.

Preliminary Results

Data collection is still in progress at this point (Summer 1987), but several relationships have been observed. The reader is cautioned about relying on the preliminary observations, pending the complete quantitative analysis of data.

Traditional Impact Sites

Manipulative behavior includes (1) the building of a rock fire ring, (2) construction/stocking of a woodpile and (3) the general "humanizing" of the area by arranging logs or rocks to form a fire circle or the removal of tufts of grass to form a smoother tent site. Measurement variables directly affected by manipulative behavior include human artifacts, loss of downed wood and changes in herbaceous vegetation/bare ground area.

The greatest amount of change occurred during treatment weeks 1 and 2 as a result of manipulative behavior patterns. During this period, the fire ring was constructed from nearby rocks, onsite downed wood including branches from logs too big to move were broken off to form a woodpile, and logs were carried onto the site to form benches around the fire. During treatments 3 through 9, manipulative behavior was less evident, mainly consisting of restocking the woodpile or making minor changes in the position of the log benches that formed the fire circle.

A circular impact pattern centered on the fire ring developed even though the campsites were rectangular. The rate of impact per treatment was greatest for herbaceous vegetation within the fire circle and at tent entrances. It is speculated that the wearing of lug soled shoes in camp impacted tent entrance areas more forcefully than soft soled shoes, resulting in bare ground formation. Within the fire circle, the amount of bare area increased from .4 m2 after treatment 2 to 1.6 m2 after 4 treatments. Further, the vegetation/visual impact rating within the fire circle dropped from an impact level of flattened and green after 1 treatment to flattened and brown after 4 treatments. The mean vegetation/visual impact zone ratings for traditional impact sites 1, 3, and 6 after 4 treatments were estimated as: bare ground, 2%; litter, 6%; vegetation flattened and brown, 25%; vegetation flattened and green, 44%; and vegetation erect, 21%.

During treatments 5 through 9, expansion of the impact zone areas bare ground and litter were observed within the fire circle. The overall appearance of the site continued to deteriorate visually from off site areas. Vegetation became flattened across the whole site with the exception of untrampled islands, whereas, offsite vegetation remained erect.

Minimum Impact Sites

The amount of impact appears to be cumulative on minimum impact sites for the variables: herbaceous vegetation and bare ground. The greatest amount of change occurred at tent entrances. A bare area 0.4 m2 developed after the fifth treatment on site 5. It is speculated that this was the most popular position for the tent entrance. It was also noted that at this site the vegetation appears less "vigorous" due to lower soil moisture levels. The effect of soil moisture levels and vegetation response to impact will be monitored further.

Minimum impact sites 2 and 4 did not develop bare ground areas, as exhibited on site 5. The mean vegetation/visual impact ratings for minimum impact sites 2, 4, 5 after four treatments were estimated as: vegetation flattened and brown, 1%; vegetation flattened and green, 33%; and vegetation erect, 66%.

Conclusions

Many questions remain unanswered at this stage of the project. The second year of the study will hopefully help to delimit the relationships among type of camping behavior, amount and rate of impact, and the carrying capacity at wilderness campsites.

It appears that manipulative behavior, i.e., the building of a fire ring on traditional impact campsites, accounts for greater amounts of impact over a shorter time period because activity is concentrated around the fire ring. Whereas, on minimum impact campsites manipulative behavior is lacking, resulting in less severe vegetative and visual impacts. The greatest amount of change on minimum impact sites occurs at tent entrances where bare ground areas may develop due to concentrated activity.

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The Application of Video/Photographic Remote Sensing to Recreation Resource Management: An In-Progress Report

John R. Watson, Glenn Haas, and James K. Lewis[1]

Abstract--Increasing recreational impacts upon our natural resources is occurring during periods of both fiscal austerity and strict environmental mandates. Thus, alternative methods are needed to aid resource managers in their decision making. New advances in video and photographic remote sensing technologies may help compensate for this dilemma. This current project will contrast satellite, video/photographic, and ground truth data from alternative passages of hikers, horse-back riders, and off-road vehicles in prairie and subalpine ecosystems. Additionally, recent developments in image processing will be tested for their relevancy to recreation resource management.

Since the late 1960s, recreational use and resource demands have steadily increased on the 700 million acres administered by federal and state public land agencies. Concomitantly, the promulgation of environmental legislation along with budget cuts have strained the conventional methods of data acquisition which managers have heretofore utilized to monitor and ameliorate recreational impacts. It is our contention, that new user friendly remote sensing advances and geographic data handling systems can aid in compensating for this growing dilemma.

Since 1980, the adoption of high quality yet low cost "off the shelf" video components for remote sensing has been growing with encouraging results (Curran, 1982; Everitt and Nixon, 1985; Meisner, 1986; Nixon, et al., 1985; Schumacher, 1980; Vleck, 1983). Reduced video resolution remains a problem and most video systems continue to use conventional aerial photographs for comparison purposes. Also, 35mm slides can now be digitized and converted to a video signal for processing. However, higher resolution video cameras and recorders will be on the market shortly. The advantages of video are the near real time imagery with immediate turnaround time, low cost of tape, and its compatibility with electronic data handling systems. In addition, recent advances in video image processing hardware and microcomputer software programs will allow anyone access to the technology (i.e. video-game difficulty).

[1]Watson is a Research Associate and Haas an Associate Professor in the Department of Recreation Resources and Landscape Architecture, Lewis is a Senior Research Scientist in the Department of Range Science, Colorado State University, Fort Collins, Colo.

In this instance, our research program is directed to develop and export remote sensing systems as practical, easy to use tools which any resource manager could utilize in their decision making. Thus, professionals who have no experience or interest in remote sensing, computer or image processing theory could use this system in a practical problem solving manner. It must be stated that while this technology represents a promising approach to recreational resource monitoring, it will not replace ground monitoring efforts. However, as stated by Anderson et al., (1980), "one of the major benefits of surveys supported by remote sensing, compared with those based only on traditional groundwork, is the capability to extrapolate information from sample sites to unsampled, remote areas."

Background

In January 1987, our McIntire-Stennis project (Watson and Haas, PI's) entitled "A convergent validation study utilizing video and photographic remote sensing techniques for the assessment of recreational-induced impacts" pooled resources with a NASA project (James Lewis, PI-CSU; Lee Miller, PI-U of Nebraska) entitled, "Modeling energy flow and nutrient cycling in natural semi-arid grassland ecosystems with the aid of thematic mapper data." In both studies, a multistage sampling scheme is underway consisting of ground truth data (stage 1), low flying aircraft for video/photographic data (stage 2) and satellite thematic mapper data (stage 3). Both of these projects are currently underway at the ARS Central

Plains Experimental Range (CPER) within the Pawnee National Grasslands in Colorado. In addition, the McIntire-Stennis project will be duplicated, minus stage 3 sampling, at a subalpine site during the summer of 1988.

Experimental Procedures

Ground Truth

Over two summer periods, ground data will be collected at each study site, respectively (prairie 87 and subalpine 88) before and after each imagery session. At each study site five, contiguous, rectangular plots are established and non-overlapping treatments applied similar to those of Weaver and Dale (1978) comparing different levels of trail travel impacts upon grasses caused by hikers, horses and trail bikes. A randomized complete block design is used to reduce confounding from plot gradient bias. Experiments at both study sites will be replicated for each treatment (hiker, horse, off-road vehicles) at low (100,300), medium (500,700) and high (1000,1200) trampling passages.

Five transects are located equidistant across each trail where one meter quadrats are placed at trail center for sampling. Prior to treatment application and at all treatment levels, the following parameters are being examined: percent bare ground; trail width; trail depth; herbaceous biomass; total chlorophyll; and spectral reflectivity. This information will then be correlated with the remote sensing data.

Remote Sensing

A Xybion[2] MSC-02 solid state multispectral video camera is being used which has the unique capability of sequentially capturing images in up to six different user-defined spectral regions. This is accomplished through the use of a rotating filter system between the lens and the CCD imager. This system contains a user-changeable filter wheel with six different filters. Four of the filters closely match the band pass of the first four landsat bands. One filter removes wavelengths longer than 0.43um and the last one allows the full range of sensitivity of the camera to be imaged (0.4um - 1.1um). The lens is a Nikkor[2] 20mm f2.8 in a C to Nikon[2] adapter.

The Xybion is interfaced with a portable Panasonic[2] AG 2400 portable VHS recorder with a JVC[2] TM-22U portable monitor. In addition, the aerial package contains a Spectron[2] CE 590 spectroradiometer allowing measurement of 256 reflectance bands with each of two Spectron CE 390 heads with 1 field of view (wide band .400 to 1.080um and a UV .200 to .440um). A portable oscilloscope is also included. For ground truthing, the Spectron can measure 1 cm^2 homogeneous areas with the 1 lens and larger plots with a 10° lens from a tripod at the quadrat sites in each treatment area. This will allow statistical comparison of reflectance data among treatment means and for comparison with aerial reflectance data. Lastly, a 35mm Nikon[2] F3 with an MD-4 motor drive and Nikon[2] 105mm f2.8 lens is being used in conjunction with the video system.

An aircraft mount was built to fit on the seat rails of any Cessna and extend out the right door (fig 1). In this case it is a Cessna 210 turbo owned by CSU flown with the right front seat removed and a modified right front door allowing the instrument package to stick out the bottom portion. The mount holds the video camera, one spectroradiometer head, and one Nikon camera. An instrument rack is mounted in place of the left seat in the second row of the aircraft. This rack holds the video recorder, the video monitor, the spectron CE 590, and the oscilloscope. The instruments were bore sighted and temporally synchronized using a battery-powered relay separated from the spectroradiometer data analyzer with a diode. This relay energizes all instruments, the camera trigger on the CE 590 starts the video and triggers the Nikon as the spectroradiometer cycles. Cycling continues with one scan and a 35mm exposure every 7 seconds until the magnetic tape on the CE 590 is full or until 36 exposures have been made on the Nikon. A digitizer board from Xybion (ImCap 01) will be used with Xybion software to digitize and display the video images on an Electrotome2 ECM 1311 color monitor.

The Mapping and Image Processing System[2] (MIPS) developed by the NASA project co-investigator (Lee Miller) using a Vectrix[2] VXPC-B graphics controller will be used for video image and data processing. This software represents the user friendly interface between the remote sensing technology "mystique" and the basic information needed for resource management applications. MIPS can be retrofitted to IBM[2] PC compatible microcomputers and has a wide range of functions (including GIS mapping features) for specific analyses of satellite, video and photographic imagery. In this study, detection of trampling impacts will be analyzed using MIPS. The MIPS software would produce an appropriate picture on the monitor of the impacted scene from the remote sensing tapes or digitized slides. Either the entire scene or subscene may then be examined. For example, with color infrared film we could compute the area selected into a 10 step green biomass map, color coded and displayed with appropriate areas for the 10 levels. Certain levels would represent the impacted areas. Features mapped are reported in percent, acres or some other measurement unit selected by the user. This process is accomplished with a mouse which can direct a special cursor to one special area on the screen. That prototype pixel trains one of the systems algorithms to identify other similar pixels throughout the scene (which could represent many acres). Those pixels matching the prototype are then color coded and measured (fig. 1d).

[2]The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

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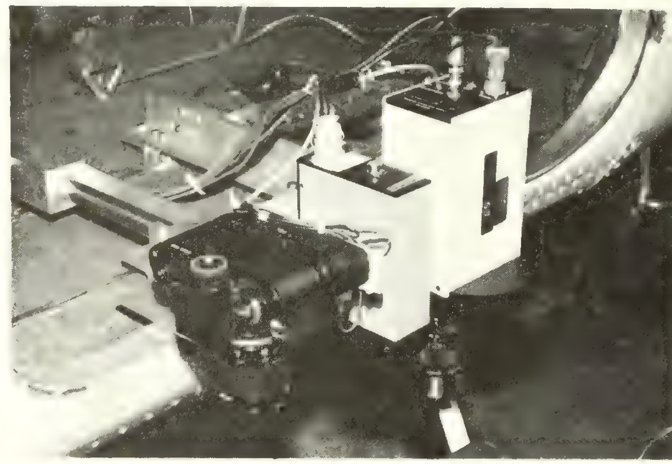
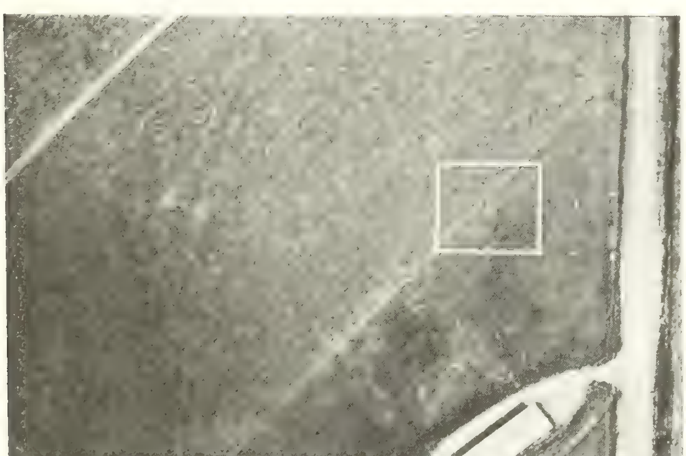


Aircraft Instrument Package (a,b), 35mm



Natural Color Image, October 1986 (c)

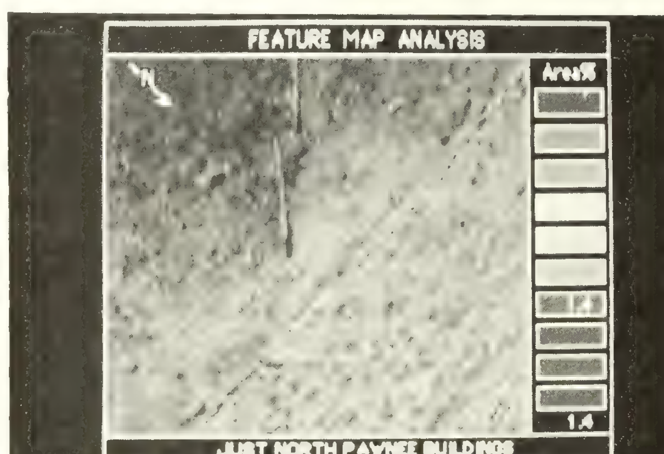


Image in (c), Digitized and Classified (d)

Figure 1.--Photograph (a) shows Cessna aircraft with right door removed to accomodate the floor camera mount. Photograph (b) shows the instrument package - from left to right, Nikon F3 35-mm, Spectroradiometer, and Xybion multispectral video camera. Photograph (c) is a 35-mm (3400' AGL) image of a shortgrass prairie site, outlined areas is magnified in image (d). Outlined area from photograph (c), digitized and displaying a bare soil classification.

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Factors Affecting Snowmelt and Streamflow

W. U. Garstka[1]

The excellent collaboration between the Bureau of Reclamation and the Forest Service, as evidenced by a report on the Cooperative Snow Investigations at the Fraser Experimental Forest,[2] had its inception at the "First Conference of Engineers" of the then newly organized Reclamation Service, which was held at Ogden, Utah, September 15 to 18, 1903.

Gifford Pinchot, Chief Forester of the Forest Service, spoke at this conference, and his presentation is quoted in part as follows.

> "For the present, much of the most important use of the forest reserves is to supply water to the irrigator, and their utility in this respect should be preserved in every possible way. This use, too, will increase with time, and it will become more and more evident that the foundation of the irrigation development of the West lies in the wise administration of the forest reserves. Not only can the present supplies of water be conserved by the right handling of the forest, but there is no question whatever that in many localities they may be largely increased."

Although few men are alive today who comprised the Reclamation Service and the Forest Service on the date when Gifford Pinchot attended the meeting at Ogden, the basic concepts on the development of natural resources that inspired the workers of that day stand forth today with undiminished brilliance as guiding lights in the endeavor to attain more intensive and efficient utilization of the Nation's water resources.

The report on the Cooperation Snow Investigations summarized the work done and the analyses made with data collected at the Fraser Experimental Forest, Fraser, Colo., during the snowmelt seasons of 1947 to 1953, inclusive. The Bureau of Reclamation and the Forest Service collaborated in these cooperative snow investigations. Comparisons between the catch in Sacramento-type storage precipitation gages and the accumulation of snow on the ground indicated that the gage catch was generally deficient. Charts compared degree-days computed from daily maximum and minimum temperatures with degree-days indicated by thermograph traces. Analyses of the runoff hydrographs showed the major importance of long-term recession flows in the snowmelt hydrograph. Relations were developed between the daily snowmelt hydrograph and the melt-causing meteorological factors that led to the development of techniques for forecasting the shape of the snowmelt hydrograph on a daily basis. The relation of area of snow cover to the resulting hydrograph was explored for 1 year when detailed mapping of the snow covered area was pursued. The effect of evaporation during the snowmelt season was analyzed by use of Light's equation.

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Newell, F. 1904. Proceedings of the First Conference of Engineers of the Reclamation Service with accompanying papers. Geological Survey, Water Supply and Irrigation Paper No. 93.

[1]Engineer (retired). U.S. Bureau of Reclamation.

[2]Garstka, W. U., and others. 1958. Factors affecting snowmelt and streamflow: a report on the 1946-1953 cooperative snow investigations at the Fraser Experimental Forest, Fraser, Colo. Washington, DC: U.S. Govt. Print. Off. 189 p.

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

Forest Service, U.S. Department of Agriculture

Rocky Mountain Forest and Range Experiment Station

Secretaria Agricultura y Recursos Hidraulicos

Instituto Nacional de Investigaciones Forestales y Agropecuarias

General Technical Report RM-150

STRATEGIES FOR CLASSIFICATION AND MANAGEMENT OF NATIVE VEGETATION FOR FOOD PRODUCTION IN ARID ZONES

ESTRATEGIAS DE CLASIFICACION Y MANEJO DE VEGETACION SILVESTRE PARA LA PRODUCCION DE ALIMENTOS EN ZONAS ARIDAS

October 12-16, 1987
Tucson, Arizona

USDA Forest Service
General Technical Report RM-150

December, 1987

Strategies For Classification and Management of Native Vegetation For Food Production in Arid Zones

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October 12 - 16, 1987
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Technical Coordinators:

Earl F. Aldon
Carlos E. Gonzales Vicente
William H. Moir

Cosponsors

Mexico:
Subsecretaria Forestal, a traves del Instituto Nacional de Investigaciones Forestales y Agropecuarias

United States:
Rocky Mountain Forest and Range Experiment Station, and Southwestern Region, Forest Service, U.S. Department of Agriculture

Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

ABSTRACT

Aldon Earl F., Gonzales Vicente, Carlos E., Moir, William H., Co-editors. 1987. Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones: symposium proceedings; 1987 October 12-16; Tucson, Arizona. Gen. Tech. Rep. RM-150. Fort Collins, CO : U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 1987. 257 p.

These proceedings contain 44 papers presented as part of a continuing cooperative effort in forestry and related resources between Mexico and the U. S. Sessions were held on arid land classification, sampling techniques, utilization of native plants, soil management, desertification, agrosilvicultural systems and watershed management.

Papers are in the language of the author (Spanish or English) with an abstract in the other language.

Keywords: Arid land plants, desert agriculture, desertification.

RESUMEN

Aldon, Earl F., González Vicente, Carlos E., Moir, William H., Co-editores. 1987. Estrategias para la classificación y el manejo de vegetación nativa para la producción de alimentos en zonas áridas: Memoria del Simposio; del 12 al 16 de Octubre de 1987; Tucson, Arizona. Gen. Tech. Rep. RM-150. Fort Collins, CO : Servicio Forestal del Departamento de Agricultura de los E.U.A., Estación Experimental Forestal y de Manejo de las Montañas Rocallosas. 257 p.

Esta memoria contiene 44 ponencias presentadas como parte de un esfuerzo continuo de cooperación sobre Dasonomía y sus recursos asociados entre México y Estados Unidos de América. Las sesiones versaron sobre clasificación de zonas áridas, técnicas de muestreo, utilización de plantas nativas, manejo de suelos, desertificación, sistemas agrosilviculturales y manejo de cuencas.

Las ponencias se presentan en el idioma del autor (español ó inglés) con un resumen en el otro idioma.

Palabras para codificación: Plantas de zonas áridas, agricultura del desierto, desertificación.

PREFACIO

En 1981 el Servicio Forestal del Departmento de Agricultura de Estados Unidos de América y la Subsecretaría Forestal de la Secretaría de Agricultura y Recursos Hidráulicos de México, firmaron un plan de cooperación para intercambiar información que permitiera mejorar la capacidad profesional y técnica de los científicos de ambos paises. El plan incluye la organización de simposios, el primero de éllos se realizó en Saltillo, Coahuila, México en 1985.

Estrategias para la Clasificación y Manejo de la Vegetación Nativa para la Producción de Alimentos en Zonas Aridas fué el segundo simposio, el cual se llevó a cabo en Tucson, Arizona, E.U.A. Las ponencias presentadas durante los tres días del evento, con un día dedicado a un viaje de campo al Area Experimental de Santa Rita y a la de la Cuenca Experimental de Walnut. Mas de 130 científicos, técnicos y administradores participaron en este simposio. Este informe técnicio general incluye las ponencias presentadas en el idioma del autor (inglés o español) con un resumen al final en el otro idioma.

Las reuniones internacionales requieren de una preparación cuidadosa y se involucra a mucha gente. Se dió reconocimiento por el éxito del simposio en Tucson a: Avelino B. Villa-Salas y Heriberto Parra Hake del Instituto Nacional de Investigaciones Forestales y Agropecuarias, a George Garcia, Bob Partido, Reggie Fletcher, Bob Hamre y Liz GarcíaSánchez del Servicio Forestal del USDA. Carlos González fué la contraparte en México para la organización de la reunión y la selección de ponencias. Todos los trabajos que se presentaron representan la opinión de sus autores, quienes son responsables de sus puntos de vista, preparación de manuscritos y edición.

Foreword

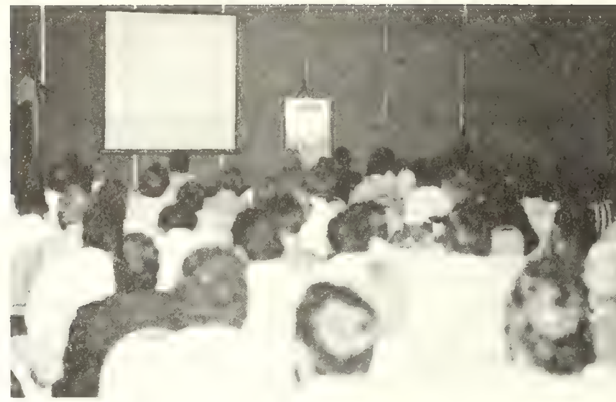
In 1981, the USDA Forest Service and SARH Sub-secretaria Forestal de Mexico signed a plan of cooperation to exchange information to improve the professional and technical capabilities of scientists in both countries. The plan included sponsorship of symposia, the first of which was held in Saltillo Mexico in 1985.

"Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones" was the second symposium held October 12-16, 1987 at Tucson, Arizona. Papers were presented during this three day meeting with one day devoted to a field trip to the Santa Rita Experimental Range and the Walnut Gulch Experimental Watershed. Over 130 scientists, technicians, and administrators attended the symposium. This General Technical Report includes papers presented in the language of the author (English or Spanish) with a summary at the end of the proceedings in the other language.

International meetings require considerable preparation and the involvement of many people. Recognition for the successful symposium in Tucson must be given to Avelino B. Villa-Salas and Heriberto Parra-Hake from the Instituto Nacional de Investigaciones Forestales Y Agropecuarias, and George Garcia, Bob Partido, Reggie Fletcher, Bob Hamre, and Liz GarciaSanchez from the USDA Forest Service. All the papers presented represent the opinion of individual authors, who were responsible for their own peer review, manuscript preparation, and editing.

EARL F. ALDON, CARLOS GONZALES, AND WILL MOIR, Co-Editors.

Registering



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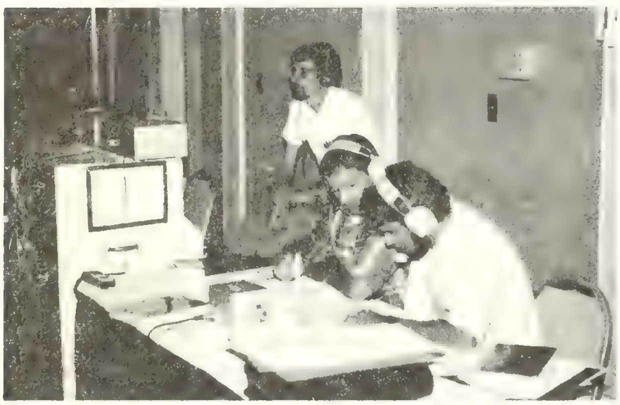

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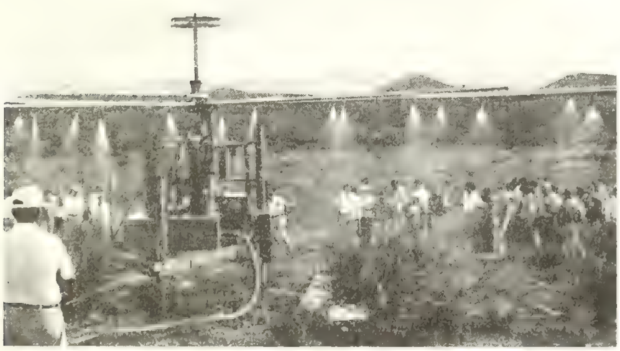

"Raining"

Socializing

Earl Aldon

Carlos Gonzales

Charles Loveless

Will Moir

Sotero Muniz

Contents INDICE

Desertification DESERTIFICACION

Agro-Silvicultural Systems SISTEMAS AGROSILVOPASTORILES

Halophytic Food Crops for Arid Lands[1]

James W. O'Leary[2]

Abstract.--Halophyte domestication would make extensive "new" sources of water available for food crop production. High productivity of valuable agricultural commodities from halophytes irrigated with highly saline water has already been demonstrated, but the soil/water management aspects of saltwater agriculture still have not been adequately addressed and may be the major limitation to widespread adoption.

INTRODUCTION

Food crop production will, of necessity, undergo significant changes in the coming years as fresh water becomes increasingly less available for agricultural use. Some of these changes, such as more efficient delivery and application systems for irrigation water, are already evident and will continue to be of importance in the struggle to maintain agricultural productivity high with decreasing supplies of fresh water. Still in the early stages of development but expected to eventually be a widespread practice is multiple use of irrigation water (Rains et al., 1987; Grattan et al., 1987). This will enable two or more crops to be grown with the same amount of fresh water that heretofore has been used to grow one crop.

Not nearly so evident as these engineering-type changes, but of equal, or even greater, need in the future are changes in the crops themselves. Drought resistant varieties of some crops have been developed, which do permit production with less water than that required for the less resistant varieties. However, there is a feeling that the water requirement might be reduced considerably more if plants native to arid or semi-arid areas could successfully be cultivated as food crops. That is not necessarily so, however. Those plants that persist in areas that receive scant and/or unpredictable rainfall possess attributes enabling them to survive and grow with low water requirements, but the price that usually is paid by those plants for the ability to survive such drought-prone environments is relatively low growth rates. This could impose serious constraints on the utilization of such plants as crops. To a certain extent, survival and growth are opposing strategies. Growth depends on assimilation of carbon dioxide from the atmosphere, which requires open stomates with the inevitable, concomitant water loss from leaves. Survival, on the other hand, depends on reduction of water loss as much as possible, which usually involves stomatal closure and thus the inevitable severe reduction or prevention of carbon dioxide assimilation.

There is yet another alternative, though. If brackish or saline water could be substituted for fresh water, then the crops could conceivably be provided with all the water they need for high productivity, since there are vast stores of such water supplies available in many areas that in other respects are highly suitable for crop production. This, of course, is contingent upon the availability of crop plants with sufficient salt tolerance. Again it can be said that salt tolerant varieties of

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some crops have been developed that permit production under salinity levels higher than those tolerated by other varieties of the same crops. However, the range of salinities encompassed by all of the present salt tolerant crops is relatively small, and none of them are suitable for use in situations involving irrigation with water having salinity levels of 10 parts per thousand (ppt) or greater. Since most of the water on the planet is even more saline than that, it seems unlikely that there will be any large "new" sources of water for agriculture if we are limited to using our present crops.

There are many plants that thrive at high salinity. They are called halophytes (literally, "salt plants"), and there are more than 1250 species in over 100 families (Aronson, 1985). This provides a large resource from which crop plants could be selected and developed for use in situations where the only water available is highly saline. Modest attempts to do that have been made at various times in the past (O'Leary, 1985), but within the past decade intensive efforts have been mounted in a few places with moderately successful progress so far.

HALOPHYTIC FORAGE CROPS

Nutritional Value

Some halophytes, such as Atriplex spp., have long been used as forage under rangeland conditions. As a result, those plants have been subjected numerous times to analysis for their feed value (O'Leary, 1987). Many halophytes have been found to have high content of crude protein (6.25 x total N), as well as low fiber content, and other attributes that contribute to their value as forages. Thus, it is not surprising that some of those halophytes have been planted in several areas to replace or supplement the existing vegetation as a means of increasing rangeland productivity.

One of the intrinsic features of halophytic vegetation is high salt content in the tissue, and this poses some constraints on its use as animal feed. Even though the tissue may be highly palatable, digestible, and nutritious, the salt content can limit the total daily consumption, and as a result, the growth rate of the animals can be very low. If the halophytic forage is the only source of food, it may not be sufficient to sustain the animals. Thus, widespread and extensive use of halophytes as forage/fodder crops likely will require blending or mixing them with other food sources.

Productivity

If halophytes are going to be cultivated as crop plants and irrigated with saline water, the productivity will have to be reasonably high, comparable to conventional forage/fodder crops irrigated with freshwater. We have measured productivity of several halophytes when cultivated and irrigated with brackish water (Watson et al., 1987) or seawater (Glenn and O'Leary, 1985). Harvested biomass yields equivalent to 17 tonnes dry weight per hectare have been obtained with some of them, which is comparable to alfalfa yields when irrigated with fresh water. Several of the halophytes tested had poor yields, however, so careful selection will be necessary. Furthermore, in general, native species did better than exotic species (O'Leary et al., 1985).

A substantial part of the dry weight of halophyte leaves is salt. For example, salt may represent 30% of the dry weight in Atriplex when irrigated with saline water, and some other genera may have salt contents as high as 50% of their dry weight (O'Leary, 1987). Thus, the true dry weight of organic matter harvested from those plants is considerably less than the reported yields.

HALOPHYTIC SEED CROPS

The salt content of seeds from halophytes is no higher than that of seeds from glycophytes, for good physiological reasons (O'Leary, 1987), no matter how high the salinity of the environment. Thus, halophytic seed crops should have none of the negative features resulting from high salt content as do the halophytic forage crops.

Nutritional Value

The potential halophytic seed crops fall largely into two categories. One is the high carbohydrate type of seed, analogous to our present grain crops. Distichlis, or salt grass, has seeds that look similar to wheat and rice, are similar in size, and have similar carbohydrate content. Seeds of this halophyte have a long history of use as human food (Felger, 1979; Doebley, 1984). As a result, it is quite possible that this could become the first major,

intensively cultivated, halophytic food crop.

The other category is oilseed crops. Many halophyte seeds have reasonably high oil and protein contents (O'Leary, 1987), analogous to our present oilseed crops such as soybeans. The attractive feature here is that there are two potential products, the extracted oil and the remaining high protein seed meal that could be used as a feed supplement for animals. Depending on the composition of the extracted oil, it could be valuable as either an industrial oil or as a vegetable oil for human consumption. The seeds of Salicornia have an oil that is high in unsaturated fatty acids, for example, so it should be a potential oilseed crop for human food production. In fact, 70% of the fatty acid content is linoleic acid (Austenfeld, 1986), which ranks Salicornia oil right up there with highly desirable vegetable oils such as safflower oil.

Productivity

Most of the halophyte seeds are rather small but the yield per plant is high, so total yield per unit area is fairly high. There are not many values for seed yield from halophytes available in the literature, but from those that are available, it looks like seed yields of approximately a tonne per hectare are possible (O'Leary, 1987).

Thus, it looks like there are some good candidates for use as halophytic seed crops that will produce reasonably good yields of highly desirable seeds when irrigated with saline water.

FUTURE PROSPECTS

Ultimately, it would be desirable to genetically improve some selections from the halophyte resource pool in much the same way that we have developed our present crop plants. For example, increase size and/or numbers of seeds or fruits per plant, and change the physical nature of the plant, such as stature and pattern of senescence development, to make the crop easier to harvest. These are long term goals, however, and the decision whether they are worth pursuing may depend largely on how successful we are in pursuing short term goals.

The short term goals are to demonstrate that halophytes can be planted in dense stands like crops, can be mechanically planted and harvested, and will have high enough productivity of a sufficiently valuable agricultural commodity when irrigated with highly saline water. The biological aspects of halophyte utilization as crops have been adequately addressed so far. It has been revealed that many halophytes have high value forage or seeds, even without genetic improvement, for example, so the prospects are high that there will be high value agricultural commodities from halophytic crops, especially after subjecting them to selection and breeding.

On the other hand, the physical or engineering aspects of growing halophytic crops have not been adequately addressed yet, and it is not easy to predict whether there will be problems revealed that could impose serious constraints on halophytic crop production with highly saline water. For example, we do not know whether agricultural soils can withstand long term application of saline water. Up to now, even when moderately saline water has been used for irrigation, the fields usually are leached sufficiently to prevent salt buildup in the soil. However, if we propose to use irrigation water with a high salinity, even with high leaching rates the steady-state salinity level in the soil will not be less than the salinity level of the irrigation water, unless it rains. Rainfall could be more of a problem than a help, however, in a soil that has been equilibrated with a highly saline irrigation water.

The sudden addition of a reasonable amount of fresh water could disrupt the salt balance enough to seriously affect soil structure and reduce permeability. This concern could impose limitations on where highly saline water irrigation could be safely conducted.

So far, most of the research on saline water irrigation of halophytes has been conducted on highly permeable, saline soils in areas where rainfall during the growing season is extremely low. Thus, most of the potential physical or engineering problems have been avoided while focussing on the biological aspects of the problems. Nevertheless, those areas will have to be addressed before halophytic food crop production with highly saline irrigation water becomes an established part of agriculture practice.

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LA IMPORTANCIA DE LAS PLANTAS SILVESTRES PARA LA PRODUCCION DE ALIMENTOS EN MEXICO[1]

Carlos E. González Vicente[2]

Resumen.- Se proporciona información general sobre la importancia de las zonas áridas en México, su extensión, población y potencial en cuanto a producción de alimentos a través de las plantas silvestres. Se hacen notar las aportaciones de las plantas silvestres del desierto a la dieta de los mexicanos que viven en ellas.

INTRODUCCION.

Por su extensión y sus recursos naturales, las zonas áridas y semiáridas, representan para México un potencial de gran importancia para su desarrollo, constituyéndose en un reto inmediato su mejor conocimiento,correcto manejo,aprovechamiento y conservación.

Se estima que las zonas áridas y semiáridas del país, cubren una superficie de 90 millones de hectáreas, equivalentes a casí la mitad del territorio nacional. Estas áreas se localizan principalmente en los llamados Desierto Sonorense, Desierto Chihuahuense y Desierto de Baja California. (Villa Salas,1980; Mc Ginnies, 1981).

[1]Documento presentado en el Simposio sobre Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas, Servicio Forestal de los E.U.A. Secretaría de Agricultura y Recursos Hidráulicos en México, Tucson, Arizona; 12 al 16 de octubre 1987.

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Se estima que en el Desierto mexicano viven cerca de 10 millones de habitantes, de los cuales cerca del 26 porciento se concentra en las 26 principales localidades, que escasamente representan el 1% del total de las mismas. El 35 porciento restante de la población habita en 34 mil pequeños poblados dispersos (SPP. 1983).

Las actividades agropecuarias y forestales, se caracterizan por desequilibrios que se manifiestan en la existencia de dos tipos generales de sistemas de producción. Por un lado, una actividad agrícola de riego, altamente tecnificada, diversificada, de carácter comercial, en la que el 60 porciento de los productores son propietarios particulares, con un uso intensivo de insumos que generan alta productividad. En contraparte, las actividades que desarrollan los productores a niveles de subsistencia, consistentes en una agricultura de temporal que se practica en casi el 80 porciento de las tierras de cultivo, una ganadería de carácter extensivo en agostaderos pobres y una actividad de recolección silvícola, que generan los más bajos rendimientos a nivel nacional (SPP. 1983).

Bajo las condiciones adversas en que viven los habitantes de las zonas desérticas, las aportaciones de las plantas silvestres a la alimentación de sus habitantes, adquieren especial relevancia. La actividad de recolección silvícola, hace aportaciones que se relacionan con la alimentación de los habitantes de las zonas áridas en forma directa, indirecta y de apoyo.

APORTACIONES DE LAS PLANTAS SILVESTRES A LA ALIMENTACION.

Los árboles, arbustos y hierbas que se desarrollan en condiciones silvestres en las zonas desérticas mexicanas, aportan alimentos que se consumen en forma directa, aprovechando sus frutos, semillas, tallos, hojas, cortezas, raíces y flores (SFF, 1982).

El consumo de una gran diversidad de plantas silvestres, debe considerarse como un mecanismo complementario que los habitantes de las zonas rurales han desarrollado, y que les permite incluir en su dieta substancias nutritivas que aportan energía, proteínas, vitaminas y minerales. (D. de Valdivia, 1982).

Como especies que aportan energía en la alimentación de los habitantes de las zonas desérticas mexicanas, pueden identificarse las raíces feculentas, entre las que destaca la "papita guera" del altiplano; o bien las azúcares, grasas y aceites vegetales y sus derivados entre los que destacan los alcoholes como el "bacanora", el "zotol" el "Mezcal" que se obtiene de diversas especies del genero Agave. (D. de Valdivia, 1982).

Se distinguen como plantas silvestres que aportan proteínas las leguminosas, entre las que destaca el "frijol tepari", el "mezquite", el "guamuchil", los "piñones" y las "bellotas de encino". (D. de Valdivia, 1982).

El grupo de plantas que aportan vitaminas y minerales es muy numeroso, y de él pueden destacarse los "quelites" que contienen hierro, la "uva silvestre", la "yuca", el "guaje", las "verdolagas", el "garambullo", los "romeritos" y las "tunas". (D. de Valdivia, 1982).

Las plantas, silvestres, también hacen aportaciones a la alimentación en forma indirecta, a través del consumo de especies forrajeras que sirven de alimento tanto a los animales domésticos como a la fauna silvestre y que constituyen un eslabon en la cadena trófica (SFF, 1982). Los forrajes de plantas silvestres, incluyen especies - herbaceas, arbustivas y arboreas, de las que principalmente son consumidos los frutos, tallos y hojas. La forma más generalizada de este consumo es el ramoneo o pastoreo directo. Son muchas las especies forrajeras y de ellas se destacan el zacate navajita, el zacatón, la cebadilla, el zacatón alcalino, el chamizo, el nopal y el mezquite.

Otro grupo de contribuciones de las plantas silvestres a la alimentación son las de carácter de apoyo, que auxilian de una u otra forma la producción y consumo de alimentos. Algunos ejemplos de estas plantas los constituyen aquellas empleadas para la elaboración de herramientas de madera, postería, empaques, carbon y leña.

Como funciones de apoyo, también deben mencionarse las que realizan las plantas silvestres en la formación y protección del suelo, la captación e infiltración de la precipitación y las relativas a la protección y al mejoramiento del ambiente (SFF, 1982).

Conviene destacar aquellas plantas silvestres presentes en las Zonas Aridas que son utilizadas con propósitos múltiples, aportando beneficios en forma directa, indirecta y de apoyo. Ejemplos de ellas son el mezquite (Prosopis spp) el guaje (Leucaena spp) que nos brindan leña, vainas comestibles, forraje, madera para construcciones rústicas, postes, nitrogenan el suelo y contribuyen a la producción apícola.

EL SISTEMA DE RECOLECCION SILVICOLA.

EL APROVECHAMIENTO DE LAS PLANTAS SILVESTRES ÚTILES PARA LA ALIMENTACIÓN EN LAS ZONAS ÁRIDAS DE MÉXICO, SE LLEVA A CABO COMO UNA ACTIVIDAD EXTENSIVA DE RECOLECCIÓN, EN LA QUE PARTICIPAN GRUPOS SOCIALES CON UN ALTO GRADO DE MARGINACIÓN Y ESCASO GRADO DE ORGANIZACIÓN PARA LA PRODUCCIÓN.

EL DESTINO QUE SE LE DA A LOS PRODUCTOS OBTENIDOS BAJO ESTE SISTEMA, ES EN MAYOR GRADO EL AUTOCONSUMO, Y SOLO EN ALGUNOS CASOS LAS MATERIAS PRIMAS OBTENIDAS SE COMERCIALIZAN A NIVEL REGIONAL, NACIONAL O INTERNACIONAL. UN BUEN EJEMPLO DE ESTE ÚLTIMO CASO LO CONSTITUYEN LA "DAMIANA" (TURNERA DIFFUSA) O EL"ORÉGANO" (LIPPIA SPP).

EN LOS PROCESOS DE RECOLECCIÓN Y CORTE DE LOS PRODUCTOS QUE EL HOMBRE OBTIENE DE LAS PLANTAS SILVESTRES EN ESTAS ZONAS EL PRODUCTOR EMPLEA SU PROPIA ENERGÍA, COMPLEMENTANDOLA EN OCASIONES CON TRACCIÓN ANIMAL. COMO HERRAMIENTA SE UTILIZA EL HACHA, EL MACHETE, COSTALES, CUERDAS Y SUS PROPIAS MANOS.

LAS ACTIVIDADES DE RECOLECCIÓN SE DESARROLLAN POR GRUPOS SOCIALES CON UNA GRAN DIVERSIDAD DE ESQUEMAS DE ORGANIZACIÓN Y DE TRADICIONES CULTURALES, EN LAS QUE PARTICIPAN TANTO EL JEFE DE LA FAMILIA, COMO LAS MUJERES Y LOS HIJOS. (INIFAP, 1987).

LAS PLANTAS SILVESTRES SE RECOLECTAN EN FORMA EXTENSIVA, BUSCANDO LAS POBLACIONES NATURALES DE LAS ESPECIES DE INTERÉS Y UTILIZANDO COMO APOYO LA TRACCIÓN ANIMAL PARA LOS DESPLAZAMIENTOS Y CONCENTRACIÓN DE LOS PRODUCTOS QUE TIENEN CIERTO GRADO DE INTERCAMBIO Y COMERCIALIZACIÓN. (INIFAP. 1987).

EL APROVECHAMIENTO DE ALGUNAS DE LAS PARTES DE LAS PLANTAS, PRINCIPALMENTE DE FRUTOS, SEMILLAS, TALLOS Y RAÍCES, ALTERA LOS PROCESOS REPRODUCTIVOS Y CONSECUENTEMENTE MERMA LA CAPACIDAD DE REGENERACIÓN DE SUS POBLACIONES, ALEJANDOLAS DE LOS NÚCLEOS URBANOS EN LAS REGIONES EN QUE SE DISTRIBUYEN. (INIFAP, 1987).

PERSPECTIVAS Y ORIENTACIONES FUTURAS.

BASADAS EN LAS TENDENCIAS ACTUALES, LA POBLACIÓN TOTAL DE MÉXICO EN EL AÑO 2000 SERÁ DE CERCA DE 100 MILLONES DE HABITANTES, DE LOS CUALES CERCA DEL 80 PORCIENTO INTEGRARÁN EL COMPONENTE URBANO, LO QUE SIGNIFICA UNA REDUCCIÓN PROPORCIONAL DE LAS PERSONAS DEDICADAS A LAS ACTIVIDADES DE TIPO RURAL. PUEDE ESTIMARSE QUE AL INICIO DEL PRÓXIMO SIGLO, MÁS DE 15 MILLONES DE MEXICANOS VIVIRÁN EN LAS ZONAS ÁRIDAS Y SEMIÁRIDAS DEL PAÍS, DEMANDANDO CONSIDERABLES CANTIDADES DE ALIMENTOS A PRECIOS ACCESIBLES Y EN CANTIDADES SUFICIENTES. (INIFAP. 1987).

LAS PLANTAS SILVESTRES DEBEN CONSIDERARSE COMO UN COMPLEMENTO QUE PUEDE AUXILIAR A SATISFACER LAS NECESIDADES ALIMENTARIAS DE LA HUMANIDAD. YA SEA APROVECHANDO LAS POBLACIONES NATURALES MEDIANTE UN MANEJO INTENSIVO DE ELLAS, DOMESTICANDO ALGUNAS ESPECIES MÁS PROMISORIAS.

EN RELACIÓN A LOS PROCESOS TRADICIONALES DE APROVECHAMIENTO, DE CONTINUAR LAS TENDENCIAS ACTUALES, SE ESTIMA QUE ALGUNAS ESPECIES ESTARÁN EN LA CATEGORÍA DE AMENAZADAS DE EXTINCIÓN O INCLUSO PODRÁN EXTINGUIRSE. POR OTRA PARTE, LAS TÉCNICAS DE APROVECHAMIENTO MUY PROBABLEMENTE CAMBIARÁN SOFISTICADAMENTE AL INCLUIR HERRAMIENTAS Y EQUIPOS MÁS EFICIENTES, QUE PERMITIRÁN AL HABITANTE DE LAS ZONAS DESÉRTICAS REALIZAR UNA ACTIVIDAD MENOS ARDUA Y MÁS PRODUCTIVA.

ES DE ESPERARSE QUE EL NÚMERO DE ESPECIES SILVESTRES EN APOYO A LA ALIMENTACIÓN Y A LOS VOLÚMENES APROVECHADOS DE ELLAS, CREZCAN PAULATINAMENTE, INCLUYENDO EN LA DIETA DE LAS FAMILIAS MEXICANAS NUEVAS ALTERNATIVAS. ASÍ MISMO, LOS PROCESOS DE ORGANIZACIÓN PARA LA PRODUCCIÓN, COMERCIALIZACIÓN E INDUSTRIALIZACIÓN, AVANZARÁN PROGRESIVAMENTE, IDENTIFICANDOSE INCLUSO MEJORES ALTERNATIVAS DE EXPORTACIÓN DE LAS QUE ACTUALMENTE TIENEN ALGUNAS PLANTAS COMO EL ORÉGANO, LA DAMIANA O LA JOJOBA.

ALGUNAS ORIENTACIONES FUTURAS EN RELACIÓN AL USO DE LAS PLANTAS SILVESTRES ALIMENTICIAS EN LAS ZONAS ÁRIDAS, DEBERÁN CONSIDERAR LOS SIGUIENTES ASPECTOS:

- LAS INSTITUCIONES CIENTÍFICAS Y ACADÉMICAS DEBERÁN REDOBLAR SUS ESFUERZOS PARA LOGRAR UN MEJOR CONOCIMIENTO DE LAS PLANTAS SILVESTRES QUE APOYAN LA ALIMENTACIÓN. EN ESPECIAL LOS ESTUDIOS RELATIVOA A SU CARACTERIZACIÓN, INVENTARIOS, MANEJO, DOMESTICACIÓN Y APROVECHAMIENTO.

- ESPECIAL CUIDADO REVISTEN LOS TRABAJOS ORIENTADOS A REGISTRAR Y RESCATAR LOS USOS Y MANEJO DE UN GRAN NÚMERO DE ESPECIES EMPLEADAS POR LAS COMUNIDADES RURALES DESDE ÉPOCAS INMEMORIALES.

- LOS PROGRAMAS DE ASISTENCIA TÉCNICA Y EXTENSIÓN, DEBERÁN INCLUIR TÉCNICAS DE MANEJO Y APROVECHAMIENTO DE ESTAS ESPECIES COMO ALTERNATIVAS FACTIBLES PARA LAS ZONAS ARIDAS.

- PARA ASEGURAR LA EXISTENCIA DEL GRAN ACERVO GENÉTICO QUE ESTAS ESPECIES REPRESENTAN, DEBERÁN EMPRENDERSE PROGRAMAS MUY AGRESIVOS DE CONSERVACIÓN "IN SITU" Y "EX SITU".

- EL USO DE ESTAS ESPECIES DEBERÁ ESTAR REFORZADO POR UN AMPLIO PROGRAMA DE TECNOLOGÍA DE ALIMENTOS Y DE PROMOCIÓN DE SU CONSUMO.

- SE DEBE CONSIDERAR COMO MUY CONVENIENTE LA PROMOCIÓN Y DIFUSIÓN DEL USO DE LAS PLANTAS SILVESTRES DE PROPÓSITOS MÚLTIPLES.

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An Ecological Approach to Classifying Semiarid Plant Communities[1]

Richard E. Francis and Earl F. Aldon[2]

Abstract.--The vegetation variables of foliar cover, density, frequency, and subsequent importance values were used with hierarchical cluster analysis to quantify and classify plant communities. As an example of the approach, plant communities were classified for a semiarid watershed in northwestern New Mexico. This approach provides a quantitative ecological base to interpret and monitor ecosystem dynamics (trend).

INTRODUCTION

Classification of natural communities has been extensively discussed and has had a crucial role in the evolution of ecological theory (Shimwell 1972). Classification provides a basis for comparing the environment with the composition of vegetation, and involves arranging stands into classes or groups which have common characteristics (Greig-Smith 1983).

Numerous classification systems have been used for different kinds of landscapes, vegetation, and interests (Bailey and others 1978; Meeker and Merkel 1984). An ecological classification system must be based on readily identifiable elements applicable to all land area. Because of this idea, the concept of potential natural vegetation was proposed (Driscoll and others 1984). Potential natural vegetation allows for the present existing vegetation and site to be projected into the future. The choice of characteristics used to classify plant communities influences whether the resultant community-types are natural or artificial entities (Whittaker 1978).

This paper presents an ecological approach to classifying existing plant communities. The example used is based on a study that was designed to define, describe, and quantify ecological phyto-edaphic communities on the Rio Puerco Watershed (Francis 1986). The phyto-edaphic communities can be used as an ecological base to develop and evaluate management schemes, including changes in vegetation, soil surface factors, soil fungi (Fresquez and others 1987), ecological stage, and soil stability. Also, ecological classification was needed to provide criteria for extrapolating quantitative research results and potential subsequent management prescriptions to broader and similar semiarid environments (Aldon and Garcia 1971), and as a basis for interpreting ecological succession (Huschle and Hironaka 1980).

STUDY AREA

The Rio Puerco watershed is a 1.6 million ha, semiarid basin in northwestern New Mexico. The watershed has a long history of settlement, heavy livestock grazing, and site degradation which began in the mid-to late 1700's (Dortignac 1960; Vincent 1984).

The specific study area, referred to as the Upper Rio Puerco Watershed, is 64 km northwest of Albuquerque. It covers approximately 207,172 ha (about 10% of the total Rio Puerco Watershed) of which 159,080 ha are administered by the Bureau of Land Management (BLM). Elevations range from 1,662 m to 2,743 m. The climate is semiarid with an average annual precipitaiton during a 20-year period ranging from 215.9 mm to 322.6 mm. Soils, described by Folks and Stone (1968) and later revised (USDA Soil Conservation Service 1977), are classified primarily as Entisols and Aridisols with sandy clay loam textures. Because soils are a major abiotic determinant of ecological sites, the successional status or ecological stage of a community should include soil-site as an interpretation determinant (Reppert and Francis 1973; Shiflet 1973).

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METHODS

Landform, soils, and vegetation were used to identify phyto-edaphic sites for sampling and as a basis for compatible classification (Brown and others 1979, Driscoll and others 1984, USDA Forest Service 1986). Five landform classes were used which were expanded from Hickey and Garcia (1964):

1. Mesas and ridge tops (uplands): Soils were residual; slopes were less than 2%.

2. Colluvial slopes: Areas usually of 10% slope or greater from which active or intermittent soil movement occurs, usually in nonaccelerated status; usually middle or upper slopes.

3. Lower colluvial slopes: Areas usually of 2-10% slope, where soil material (colluvium) from upper colluvial slopes is deposited above alluvial flats. Finer soil in suspension may pass through to allvuival flats or drain-ageways.

4. Alluvial flats: Areas of 0-2% slopes where fine textured alluvium produced a characteristic landform with distinct topographic, soil, and vegetative boundaries.

5. Breaks: Rough, broken country with unstable soils, or areas where topography was too steep for normal soil development. Critical slope angle was undefined and varied with soil texture.

Soil taxonomy and descriptions for the study area were compiled from the soil surveys of the Cabezon Area, New Mexico (Folks and Stone 1968) and the soil survey of Sandoval County, New Mexico (USDA Soil Conservation Service 1977). Site specific physical-chemical soils data are currently being analyzed for soil-vegetation relationships.

A total of 114 sample sites were selected where apparent changes in floristic aspect or plant compositon, landform, and/or soils suggested a possible change in ecological sites. The sampling procedure and site selection were based on homogeneous vegetation stands from which data were collected to quantify, identify, and classify the sites. The selection of stands was not based on lack of disturbance. The intent was to describe the existing vegetation of the study area so that (1) present ecological stage and potential natural vegetation could be determined, and (2) existing vegetation communities could be defined for monitoring trend, applying mangement prescriptions, and indentifying ecological stage.

Transects were randomly established within each sample site. The number of transects per site varied from two to five, depending upon the apparent diversity and size of the site.

The Community Structure Analysis (CSA) technique (Pase 1981) was used to determine plant species foliar cover, density, and frequency defined respectively as the percent area of the ground surface covered by above-ground plant parts projected to the ground surface, the number of plants per unit area, and the number of plots in which a species occurred expressed as percentage of the total (Greig-Smith 1983). Transects consisted of 100 5-cm by 10-cm microplots (Morris 1973) for foliar cover, and 10 0.5-m^2 circular plots for density and frequency. The microplots were systematically located every 2 m on a pace interval, and the circular plots were located at each tenth microplot. For each microplot, plant foliar cover by species was estimated using the following classes: t(trace) = 0-5%, 1 = 6-15%, 2 = 16-25%, 3 = 26-35%, 4 = 36-45%, 5 = 46-55%, 6 = 56-65%, 7 = 66-75%, 8 = 76-85%, 9 = 86-95% and 10 = 96-100%; analysis was based on class mid-points. In addition, plant litter, bare soil, and rock fragments ≧ 2.54 cm diameter were estimated according to the same cover classes. Litter was defined as loose plant debris, or standing dead material not of the current year's growth. Synusae (life-form strata) were evaluated separately. Frequency for each species was calculated using data from the 0.5 m^2 plots; possible frequency ranged from 0-100% in 10% increments. Voucher specimens were collected and verified.

Site data were analyzed and summarized using program COSAM[3], which provided a summary of plant species with associated cover, density, and frequency values; the percent cover of bare soil, litter, rock; a ranked and arrayed importance value (IV) for each species; and a diversity index (DI).

Cover (C), density (D), and frequency (F) were considered to be three significant structural components of a community, and were used to calculate an importance value (Curtis and McIntosh 1951) for each species by transect and site. These three variables represent an estimate of area, number, and distribution, respectively. Use of a single variable to describe community structure could result in over or underestimating an individual species contribution to the community (Francis and King 1987a). Therefore, an importance value for each species in each site was calculated to evaluate its contribution to and "importance" in the community. An importance value implies a species relative structural dominance and competitive status within a community.

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[3] Program COSAM (COmmunity SAMple) was developed by and is on file at the USDA Forest Service, Rocky Mountain Station, Fort Collins, Colo.

The importance values were calculated using:

$$IV_i = \frac{C_i}{\Sigma C} + \frac{D_i}{\Sigma D} + \frac{F_i}{\Sigma F}$$

where: IV_i = importance value of the i^{th} species;
C_i, D_i, F_i = mean cover, density, frequency of the i^{th} species; and
ΣC, ΣD, ΣF = the total cover, density, frequency for all sample species.

Importance values were calculated, summarized, and averaged for each species by site.

The mean importance values for each site were used to calculate resemblance coefficients and to develop resemblance matrices. The resemblance matrix consisted of dissimilarity coefficients derived from Euclidean distance coefficients (Romesburg 1984).

A dendrogram was produced using the resemblance matrix and a clustering method from Program CLUSTAN (CLUSTer ANalysis) (Wishart 1981). The clustering method used was developed by Ward (1963) and is based on the minimum variance between two sites (Romesburg 1984). The cluster routine followed a hierarchical-agglomerative-polythetic approach (Goodall 1978; Romesburg 1984). To develop meaningful and realistic clusters, only species having an IV ≧ 0.1 were used, which appeared to include species that dominated the sites.

That resultant dendrogram was evaluated for realistic clusters using successive approximation (Poore 1962) and original site data summaries. Clusters were evaluated as to their separation of lifeform (tree, shrub, grass) and grouping of dominant species by site. Inter-cluster versus intra-cluster variability based on Euclidean distance was compared (Dyer 1978) as an index to significant clusters (Francis and King 1987b).

The advantage of cluster analysis is that it makes classification possible, even if it is arbitrary (Barbour and others 1980). Cluster analysis still requires that the investigator evaluate the process and the results (Everitt 1979) using a real situation. Although cluster analysis may be subjective, it quantifies the classification process because some threshold value may be chosen as the lower limit to an association or community.

RESULTS AND DISCUSSION

The 114 sites clustered using the criteria of species IV ≧ 0.1 resulted in 45 plant communities (p.c.) in 3 formations (Francis 1986). The 45 plant communities were representative of 11 vegetation series consisting of treeland, shrubland, and grassland formations (table 1). Intra-cluster variation among sites was significant for 82% of the communities analyzed, and inter-cluster variation among communities was significant for 73% of the series analyzed (Francis and King 1987b). Therefore, the majority of sites and communities were considered statistically different and ecologically realistic as classified.

Table 1.--Plant community classification, community number and name, and number of sample sites for the Upper Rio Puerco Watershed. Taxonomy and species symbols follow Martin and Hutchins 1980, and Nickerson and others 1976, respectively. Community descriptions are in Francis 1986.

Formation	Subformation	Community	No. Sites
Treeland	Pinus	1. Pipo/CARE-Bogr	3
		2. Pipo-Pied/Bogr-Cafi	1
		3. Pied/Bogr-ERIO	1
		4. Pied-Jumo/Oppo/Bogr	1
		5. Pied/Quga/Hija-Spne	1
	Juniperus	6. Jumo/Gusa/Bogr-Hija	4
		7. Jumo/Bogr	4
		8. Jumo/Artr/Hija-Spcr	1
Shrubland	Artemisia	9. Artr/Bogr-Hija	7
		10. Artr-Gusa/Bogr-Hija	3
		11. Artr/Bogr-Hija-Spai	4
		12. Artr-Gusa/Hija-Spai	2
		13. Artr-Gusa/Bogr-Agsm	6
		14. Artr/Spcr-Orhy	1
		15. Artr-Chpa/Arfe-Bogr	1
		16. Arno-Artr/Agcr-Agsm	1
		17. Arno-Gusa/Bogr-Hija	1
	Chrysothanmus	18. Chnab/Bogr-Agsm	1
		19. Chpa/Hija-Bogr	3
		20. Chnag/Bogr-Agsm	1
	Sarcobatus	21. Save	2
		22. Save/Sihy-Agsm	1
	Ceratoides	23. Cela-Gusa/Hija	7
		24. Cela-Gusa/Bogr	3
	Atriplex	25. Atcu-Frja/Spai	1
		26. Atob/Spai-Spcr	2
		27. Atob-Gusa/Hija-Spai	2
		28. Atca/Hija	1
		29. Atca/Spai-Sihy	4
		30. Atca-Gusa/Bogr-Spcr	2
Grassland	Bouteloua	31. Bogr-Hija	2
		32. Gusa/Bogr-Hija	8
		33. Gusa/Bogr-Boer	1
		34. Bogr-Spai	1
		35. Gusa/Boer-Hija	2
	Hilaria	36. Gusa/Hija-Bogr	6
		37. Hija-Spai	5
		38. Gusa/Hija-Spcr	1
	Sporobolus	39. Spai	1
		40. Spai-Bogr	5
		41. Spai-Hija	4
		42. Gusa/Spai-Hija	2
		43. Spai-Agsm	2
		44. Spne-Boer	1
	Scleropogon	45. Scbr-Bogr	1

Initially, the plant communities were determined by setting the dendrogram dissimilarity index level (Euclidean distance) at approximately 0.565 (fig. 1). However, this dissimilarity level produced some clusters that were confounded by unlike species and lifeform. Therefore, an ordered printout of site summaries (table 2) following the horizontal dendrogram x-axis was used to determine realistic site clusters and species dominance. The sites were combined into communities based on species IV ≧ 0.1 if an individual species IV rank and lifeform dominated the site (Francis and King 1987a).

For example, the first cluster formed at index 0.565 consisted of 10 sites: 1,141, 152, 37, 136, 142, 140, 144, 143, and 145 (fig. 1).

Selecting the species by lifeform with the greatest IV from each site led to all of the sites within the same formation--shrubland. However, sites 1 and 152 were classified as Artr (Artemisia tridentata)-Gusa (Gutierrezia sarothrae)/Bogr (Bouteloua gracilis)-Hija (Hilaria jamesii) (p.c. 10) (table 2); site 141 was combined with sites 142, 140, 144, 143, and 145 and classified as Artr-Gusa/Bogr-Agsm (Agropyron smithii) (p.c. 13) (table 2); sites 37, 5, 146, 7, 9, 23, and 22 classified as Artr/Bogr-Hija (p.c. 9) (fig. 1, table 2). Note

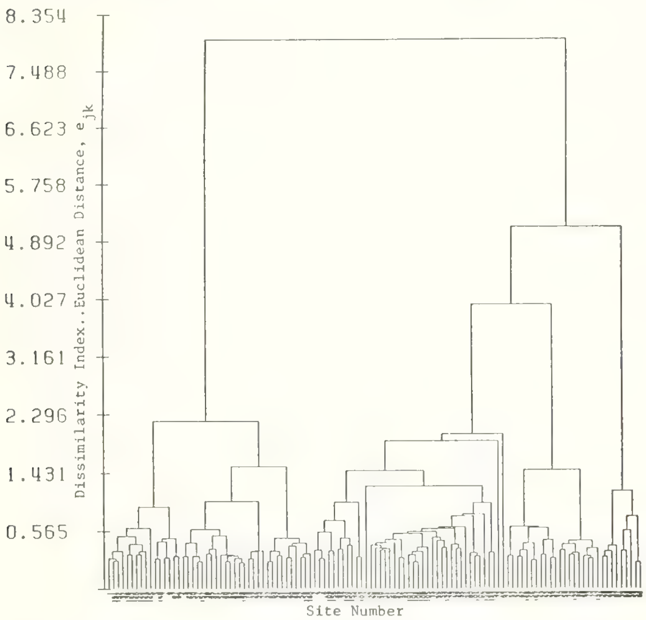

Figure 1.--Dendrogram of 114 sample sites based on importance values for all species with IV ≥ 0.1. A partial site summary and site linkage used to form plant communities are shown in table 2.

that sites 5, 146, 7, and 9 formed a realistic cluster, and that sites 37, 23, and 22 were clustered with other sites and had to be recombined using site summary data (fig. 1, table 2). For example, site 22 (p.c. 9) was clustered with site 19 (p.c. 32). Boyd (1984) also found that clusters had to be interpreted and refined to make ecologically meaningful communities.

An example of a realistic cluster requiring no additional combining was the grouping of sites 103, 104, 106, and 108 (fig. 1) which were classified as Jumo (Juniperus monosperma)/Gusa /Bogr-Hija (p.c. 6).

Clusters that confounded lifeform and species therefore required on examination using the dendrogram in relation to the site summaries. The result was 45 plant communities named for the dominant or co-dominant species by lifeform with an IV ≧ 0.1 (Francis 1986).

The hypothesis that Ward's method and dissimilarity coefficients calculated from species IV ≧ 0.1 would provide distinct, realistic clusters was rejected based on the results

Table 2.-Partial site summary of species variables following the horizontal dendrogram x-axis and site number (Fig. 2). Listed are five species with the highest IV ≥ 0.1. Underlined species were used to form and name the plant community (p.c.). Solid lines connecting the sites indicated all of the sites used to form a p.c.; broken lines indicate some of the sites.

P.C. No.	Site No.	Species	Cover(%)	Density(No.)	Frequency(%)	IV
	1	Bogr	3.8	24.3	60	.789
	1	Hija	3.2	11.0	97	.566
	1	Artr	10.5	0.7	40	.517
	1	Stne	1.6	2.3	70	.262
	1	Gusa	2.0	1.0	50	.209
10						
	141	Bogr	6.2	7.9	70	.816
	141	Artr	5.5	1.0	30	.403
	141	Agsm	1.0	4.3	35	.314
	141	Hija	0.8	4.7	20	.281
	141	Gusa	2.5	0.4	30	.277
	152	Bogr	3.9	22.9	80	.801
	152	Artr	1.7	1.5	63	.537
	152	Hija	3.4	8.7	50	.437
	152	Gusa	2.2	2.4	77	.314
	152	Sihy	0.5	4.0	63	.235
	37	Artr	12.8	1.8	80	.861
	37	Hija	3.1	17.0	90	.821
9	37	Bogr	3.7	15.6	73	.770
	37	Agsm	0.3	2.1	37	.168
	37	Agcr	0.3	0.6	20	.085
13						
	136	Bogr	24.3	16.6	80	1.373
	136	Agsm	2.0	11.9	50	.550
18	136	Hija	1.2	4.0	25	.229
	136	Spcr	0.6	1.7	35	.186
	136	Chnab	5.2	0.0	00	.138
	142	Bogr	21.7	21.6	100	1.219
	142	Artr	17.6	0.9	60	.572
	142	Agsm	1.6	15.7	80	.569
	142	Gusa	0.3	2.9	90	.278
	142	Psta	0.1	1.8	40	.134
	140	Bogr	7.7	7.7	60	.726
	140	Agsm	1.6	13.1	65	.609
	140	Hija	2.2	6.8	35	.412
	140	Artr	4.5	1.1	34	.331
	140	Spai	2.9	1.9	10	.214
	140	Gusa	0.6	0.5	20	.100
	144	Agsm	1.7	12.3	45	.500
	144	Agde	4.7	5.2	60	.489
	144	Bogr	3.8	6.2	55	.464
	144	Artr	5.0	0.9	40	.344
	144	Astr	1.7	2.5	40	.233
	144	Gusa	0.3	1.5	40	.140
	143	Bogr	9.1	16.6	00	.841
	143	Artr	12.1	2.9	70	.809
	143	Agsm	0.7	10.1	90	.604
	143	Agde	1.1	3.4	40	.272
	143	Gusa	0.2	0.4	40	.149
	145	Artr	13.2	2.8	50	1.025
	145	Agsm	2.0	16.1	40	.939
	145	Sihy	0.6	2.3	60	.390
	145	Agde	1.5	2.0	50	.381
	145	Cela	1.1	1.2	20	.195
	145	Bogr	0.2	0.0	00	.014

of this study. However, the dendrogram and associated ranked site summary data provided a realistic starting point for plant community classification.

Another analysis indicated that importance values of each species appeared to compensate for inconsistent relationships between IV variables within lifeform by using relative component values, and ranking the species importance in each community on an ecological dominance basis (Francis and King 1987a).

Therefore, it is recommended that the previously described use of the CSA method be restricted to grasslands, or modified for use in treelands and shrublands to include a larger plot size and/or nested plots for density and frequency. For example, the 0.5-m^2 plot should be nested within a 1.0- or 2.0-m^2 plot. The density and frequency of herbaceous species should be determined from the 0.5-m^2 plot, while the density and frequency of trees and shrubs would be determined from the larger plot.

The results of this study also indicated that most plant communities occurred on more than one soil series and/or association, and that most soil series and/or associations supported more than one plant community (Francis 1986). Several factors appeared to contribute to these results. First of all, the soil information was taken from mapped surveys rather than a pedon from each site being described and classified. This resulted in sample sites on such broad soil delineations that it was difficult to correlate a soil series with a plant community. Secondly, most of the soils were in the Entisol or Aridosol orders which were very young, displayed limited development, and were highly eroded. The soils have not had time to differentiate, given the climatic and biological regime. Third, the majority of plant species had a wide ecological amplitude and in most cases became established on nonspecific edaphic sites. Many species may be disturbance-induced, and perhaps are only in partial equilibrium. It is therefore recommended that the specific soil at each sample site be profiled, classified, and analyzed to develop a meaningful soilvegetation classification.

Ward's cluster analysis method provided a first approximation of site clusters necessary to form plant communities. However, supplementing that analysis with individual site summaries from Program COSAM and ecological judgement provided statistically sound and ecologically realistic clusters.

Importance values provided an estimate of plant community structure based on species areal extent (cover), numbers (density), and distribution (frequency). However, the IV's should be interpreted in relation to their component values to detect subtle ecological relationships. Dissimilarity coefficients appeared to provide adequate separation between sites, at least for a first approximation of clusters.

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A Hierarchical Classification of Landforms: Some Implications for Understanding Local and Regional Vegetation Dynamics[1]

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Abstract. Analyses of soils and vegetation on the Jornada / Long-Term Ecological Research site have shown strong relationships between vegetative communities and landforms. Observations indicate that similar vegetative patterns exist throughout the Mexican Highland division of the Basin and Range Province. A generalized landscape-level model is presented which attempts to explain the desertification trends producing the shrub - grassland vegetational mosaic found today in southern New Mexico.

INTRODUCTION

Over geological time scales, geomorphologic processes have formed the representative landforms of the Basin and Range physiographic province (Mabbutt 1977). Over periods of 10's to 100's of years, these processes can be viewed as static because of the low rate of landforming events (Allen and Star 1981, O'Neill et al. 1984). At this temporal scale, individual landforms regulate the rates of geomorphic processes, and thereby control the rates at which energy and materials (water, sediment, organic mater, propagules, and organisms) are transported within the landscape (Swanson et al. 1987).

Ecosystem studies in semi-arid and arid regions have shown that biotic processes, especially net primary production, are limited by the availability of water (Noy-Meir 1973, Crawford and Gosz 1982) and nitrogen (Pauli 1964, Cline and Rickard 1973). This paper attempts to expand on these studies by developing a framework for understanding how landscape elements influence the distribution of limiting resources within and between ecosystems. Our working hypothesis is that vegetative communities in semi-arid and arid regions should reflect differences in the horizontal redistribution of both water and organic matter between landform elements. The first objective of this paper, then, is to identify the landform elements of the Jornada Long Term Ecological Research site (LTER/Jornada); to demonstrate how these landform elements can regulate geomorphic processes that control the transport of water, sediments, and organic matter across the landscape; and to use the relationships between landform elements and geomorphic processes to attempt to explain the spatial patterns observed in vegetative communities.

Numerous studies describe the primeval vegetation of the semi-arid regions of North America as extensive grasslands with interspersed shrubs. These grasslands have been replaced by *Larrea tridentata*, *Flourensia cernua*, and *Prosopis* spp. throughout much of their former extent. These changes have often been accompanied by extensive sheet and wind erosion, and cutting of arroyo channels (Gardner 1951, Buffington and Herbel 1965, York and Dick-Peddie 1969, Stein and Ludwig 1979, Gibbens et al. 1983, Hennessy et al. 1983, Wondzell 1984, Gibbens and Beck 1987).

Several causal mechanisms have been proposed, most notably the grazing of domestic livestock (York and Dick-Peddie 1969) and climatic change (Buffington and Herbel 1965, VanDevender and Spaulding 1979, Neilson 1986); these mechanisms do act directly on vegetative communities. However, these studies usually did not consider the spatial relationships between the communities within the landscape and did not account for the interactive effects of landscape level processes.

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Landforms regulate geomorphic processes which are modified by the vegetation supported by individual landforms. Over long time periods entire landscapes converge to metastable states (Forman and Godron 1986, p. 436) at which the interactive effects of landforms, geomorphic processes, and vegetation are balanced. Our working hypothesis is that an exogenous disturbance, such as grazing or climatic change, that affects vegetation can overcome the inertia of a metastable state, leading to changes in the horizontal redistribution of water and organic matter between landform elements. The second objective of this paper, then, is to develop a generalized model which incorporates our understanding of geomorphic processes to explain the post-settlement vegetative dynamics from which the desert scrub/desert grassland vegetational mosaic of southern New Mexico resulted.

LANDFORMS, GEOMORPHIC PROCESSES, AND VEGETATION

General Setting

Landscapes within the Mexican Highland section of the Basin and Range province of North America (fig. 1) are characterized by north-south trending fault block mountains separated by broad linear valleys (Fenneman 1931, Hawley 1975).

Figure 1. Basin and Range Physiographic Province (adapted from Peterson 1981 and Ordonez 1936).

The Jornada del Muerto, which is approximately 100 km long and 30 km wide (fig. 2a & b), is a structural and topographic basin in south central New Mexico. The tectonic evolution of this basin has been accompanied by deposition of fluvial and alluvial sediments which exceed 1,000 m in depth (Gile et al. 1981). Fluvial sediments were deposited by the ancestral Rio Grande river system (Strain 1966) while concurrent erosion of the adjoining ranges resulted in deposition of alluvial sediments in extensive piedmont slopes along the mountain fronts (Gile et al. 1981).

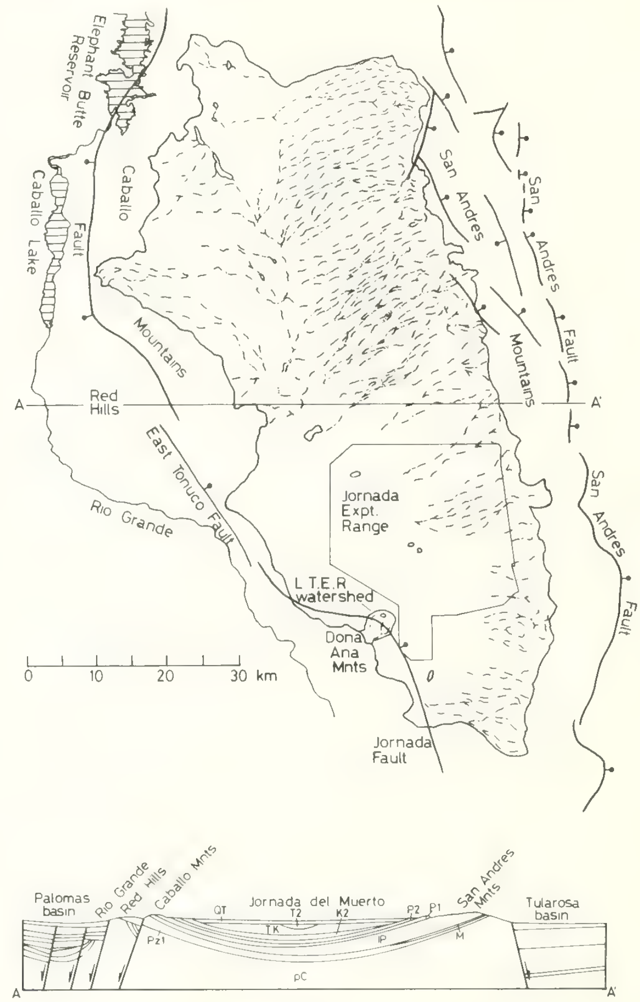


Figure 2. Jornada del Muerto. A. Structural basin bounded by faults (down thrown sides marked) and topographic basin outlined (with arroyo channels and playa lake beds shown). B. Geologic cross section showing bounding faults (adapted from New Mexico Highway Geologic Map, see for explanation of geologic symbols).

The surface of the Jornada del Muerto basin is a complex of smaller watersheds which vary in size from 1,000 to 50,000 ha. The LTER/Jornada research site traverses a 1,500 ha watershed draining the slopes of Mount Summerford, an isolated peak in the Dona Ana mountains which

border the Jornada del Muerto basin on the southwest. Two major drainage systems are present within this watershed. The LTER transects are located between these drainage systems on piedmont slopes which have been slightly dissected by localized runoff originating on the east flank of Mt. Summerford, or on the piedmont slope itself (fig 3).

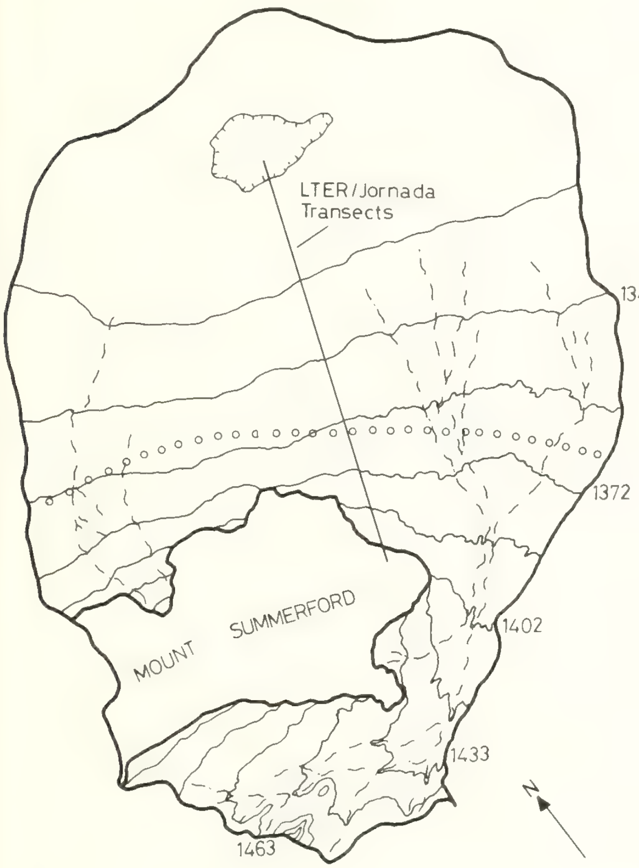


Figure 3. LTER/Jornada watershed showing location of study transects, elevations (contours in meters), and major drainages. Line of open circles represents the buried Jornada fault.

Mountain

Following Peterson's (1981) hierarchical classification, this watershed can be divided into three major physiographic parts (fig. 4), the first of which is **Mount Summerford**. It is the major source of run-off and the source of sediments within the watershed. A vertical projection of the east slope of Mount Summerford shows that precipitation is spread over a 25% greater actual surface area than would occur on a level plain. This effect, combined with the damming effect caused by the high surface roughness of bouldery slopes, allows the retention of precipitation throughout a range of low to intermediate storm intensities (fig. 5).

There is great horizontal redistribution of water between microsites on the mountain slope in all but the smallest storms. Rain falling on bare rock runs into local depressions behind barricades of boulders, which also hold sediments and organic debris deposited during larger events. These mesic microsites support a high diversity of vegetation, including species normally found under much wetter climatic conditions.

The total volume and energy of runoff increase proportionally to precipitation intensity once the flow threshold is surpassed. This is accompanied by increases in both the total sediment load and the size of sediments eroded from the mountain slope (fig. 5).

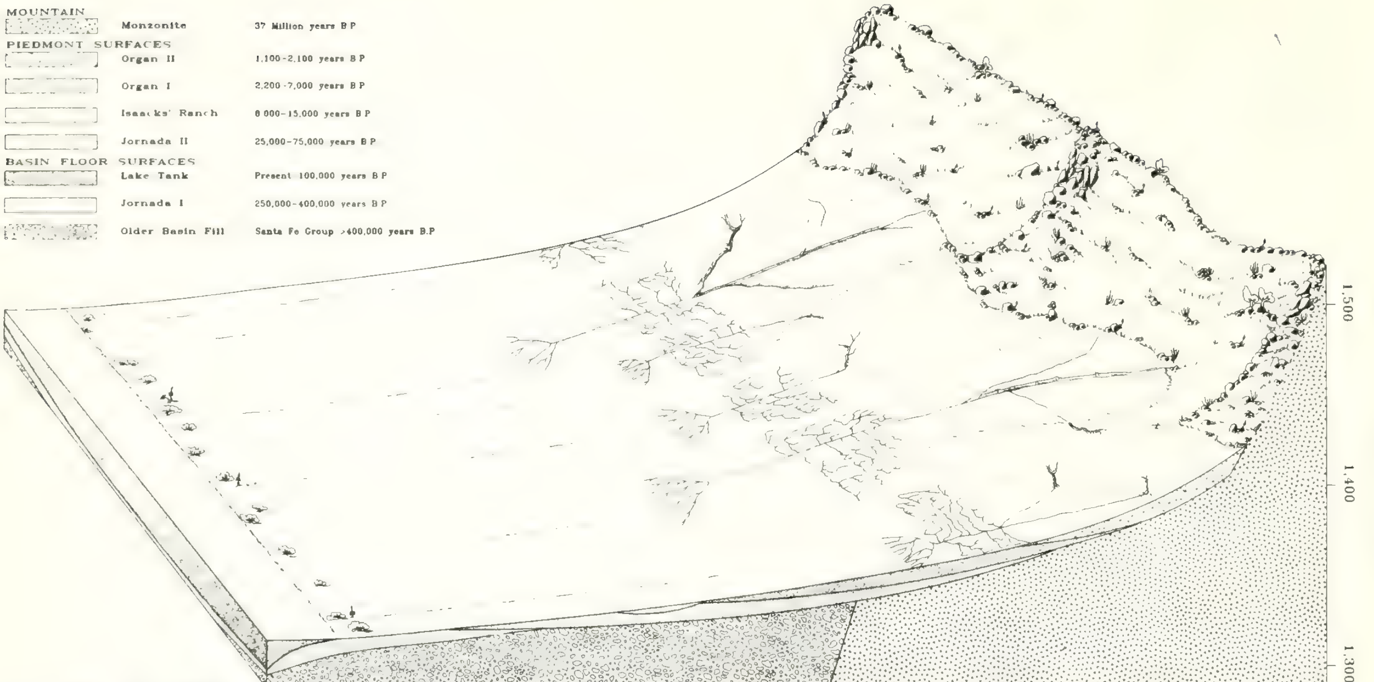
Piedmont Slope

The sediments eroded from Mt. Summerford have been deposited in a graded surface extending from the piedmont junction to the nearly level basin floor which comprises the second major physiographic part - the **piedmont slope**. The upper part of this slope is a thickly mantled, granitic **pediment** which extends from the **piedmont junction** to the buried Jornada fault, located at approximately mid-slope (fig. 4)(the structural Jornada basin lies beyond the fault). The pediment, which is unaffected by pedogenic processes and is buried deeper than either the rooting zone of most plant species or water infiltration depths, does little to affect surface processes within the watershed other than determining the gross topographic relief of the piedmont slope. In contrast, the landforms that have developed in the thick sediment mantle, resembling an alluvial fan - fan piedmont continuum, do affect surface processes. Therefore, subsequent discussion will emphasize these surface landforms.

Alluvial Fan

Fan Collar. Immediately adjacent to Mount Summerford, there is a superficial apron of loose unconsolidated sediments, known as a **fan collar** (fig. 4). The flow threshold of the fan collar should be higher than that of the mountain slope (fig. 5) due to a combination of two factors. First, the gravelly sediments have a high infiltration rate; and second, 73% of the surface area is vegetated (Table 1) (perennial grasses contribute over half of the cover). Therefore, there is a range of storm intensities which will cause runoff from the mountain without exceeding the infiltration rate of the fan collar. This runoff has developed a network of small rills that spreads the runoff across the head of the fan collar, where it infiltrates into the gravelly sediments, depositing its entire sediment load (fig. 5).

Within a few hundred meters of the mountain front the relative importance of erosional processes increases, forming small gullies.



LANDFORMS	Major Physiographic Part	Basin Floor	Piedmont Slope	Mountain						
	Major Landform	Playa	Alluvial Plain	Fan Piedmont	Alluvial Fan					
	Component Landform			Non-buried Fan Remnant	Alluvial Fan Apron	Erosional Fan Remnant	Alluvial Fan Collar			
GEOMORPHIC SURFACE		Lake Tank	Jornada I	Jornada II	Isaacks' Ranch	Organ I	Organ II			
SOILS		Dalby	Head Quarter	Bucklebar	Berino	Onite	Dona Ana	Aladdin		
VEGETATION	Type (perennial)	Playa	Fringe	Mixed Basin Slope	Creosote Shrubland	Lower Grass Land	Upper Grass Land	Rock Land		
	Sub-type (annual)			Lower	Middle	Upper				
SLOPE (%)		0.1	2.1	3.3	4.2	6.9	9 8	33 0 +		
DISTANCE (m)		300	600	900	1200	1500	1800	2100	2400	2700

Figure 4. Block diagram of the central part of the LTER/Jornada watershed that is traversed by the study transects. Classification of landforms follows Peterson (1981), geomorphic surfaces are from Gile et al. (1981), soils from Wierenga et al. (1987), vegetation is from Ludwig and Cornelius (1987), and percent slope from unpublished data (LTER/Jornada).

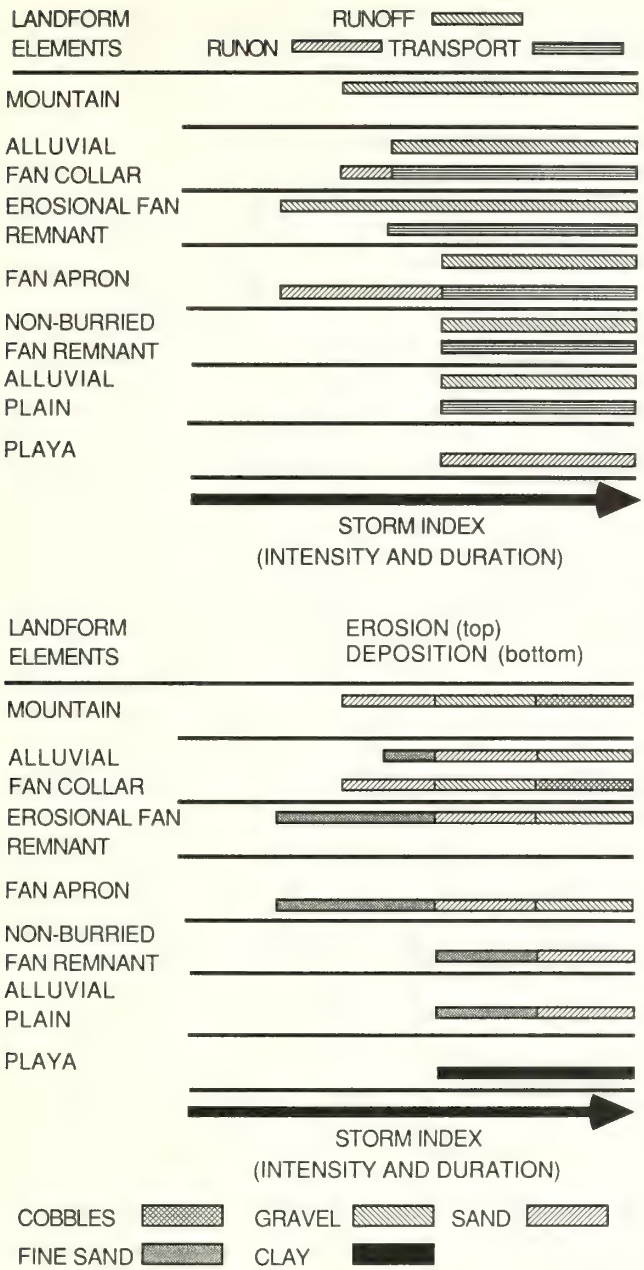


Figure 5. Hypothetical horizontal redistribution of water (A) and sediments (B) between landform elements on the LTER/Jornada watershed during storms of varying intensity.

When the precipitation intensity finally exceeds the infiltration capacity of the fan collar, runoff begins, combining with discharge from the mountain slope, and is transported out of the fan collar. However, since longitudinal gradients average only 8%, the velocity of runoff on the fan collar decreases, reducing the energy available to carry sediments. This rapid drop in energy results in the deposition of the coarse sediment fraction eroded from the mountain during these high intensity storms, even though they produce runoff from the fan collar (fig. 5).

Table 1. Percent cover of all perennial and all annual species during the fall of 1986 for each landform on the LTER/Jornada watershed.

LANDFORM	PERENNIALS	ANNUALS
MOUNTAIN	65.6	0.0
ALLUVIAL FAN COLLAR (deposit)	76.8	5.0
ALLUVIAL FAN COLLAR (erosion)	55.3	10.9
EROSIONAL FAN REMNANT	39.0	1.4
ALLUVIAL FAN APRON	35.0	40.2
NONBURIED FAN REMNANT	47.5	18.7
ALLUVIAL PLAIN	46.4	15.6
PLAYA	91.7	19.3

The fan collar supports two grassland communities (Table 1). Grasslands at the head of the fan collar are dominated by Bouteloua eriopoda - the primeval desert grassland dominant in southern New Mexico. The stability of this grassland appears to stem from several factors. First, precipitation is highly effective on these loamy skeletal soils due to the inverse textural effect (Noy-Meir 1973). Secondly, runoff from the mountain slopes frequently supplies additional water and nutrients. Lastly, nutrients appear to be retained and cycled within this vegetative community due to low surface erosion. Resulting soils have some of the highest nitrogen contents on the site (Table 2).

Table 2. Total inorganic nitrogen for each landform on the LTER/Jornada watershed (in mg kg^{-1} dry soil). Data (Fisher pers. comm.) are averaged for 9 sampling dates between 1983 and 1986.

LANDFORM	NITROGEN
MOUNTAIN	3.3
ALLUVIAL FAN COLLAR (deposit)	5.5
ALLUVIAL FAN COLLAR (erosion)	2.6
EROSIONAL FAN REMNANT	2.7
ALLUVIAL FAN APRON	4.0
NONBURIED FAN REMNANT	4.2
ALLUVIAL PLAIN	3.4
PLAYA	10.5

B. eriopoda is also important in the lower and more highly gullied portion of the fan collar, but codominates with other perennial grasses and subshrubs. Apparently, the greater relative importance of erosion and the removal of some organic matter, combined with the lack of additional runon water, sufficiently alter conditions so that pure swards of B. eriopoda cannot be supported.

Fan Piedmont

Down slope from the fan collar, lateral transport, mixing, and deposition of sediments form a **fan piedmont** (fig. 4) which can be subdivided into three component landforms **erosional fan remnant, alluvial fan apron**, and a **non-buried fan remnant**.

Erosional Fan Remnant. Finer textured sediments formerly deposited along the piedmont slope have been erosionally dissected leaving remnants of the original constructional surface known as an **erosional fan remnant** (fig. 4). This landform, with a longitudinal gradient of 4.2%, has the lowest flow threshold (fig. 5). First, finer soil textures and shallow depths to caliche (which plugs the soil horizon) reduce the infiltration rate. Secondly, vegetation covers only 34% of the surface area and two thirds of this (22%) is Larrea tridentata. Therefore, relatively low storm intensities would exceed the infiltration capacity of this landform and initiate runoff. Since longitudinal gradients are too high for sheet flow to predominate, but too low for extensive gullying, this runoff has produced a network of small rills, known as sheet rill. The few arroyo channels present in this landform head higher on the slope, and primarily transport runoff from either Mount Summerford or the fan collar through this landform (fig. 4).

This Larrea tridentata - dominated community has probably been present since pre-settlement times (Stein and Ludwig 1979). Apparently, the overall characteristics of the watershed lead to a dominance of erosional processes (fig. 5) which maintain the shrub community. Leaves dropped from the shrubs build up around the rootcrown of the plants, where the soil surface is protected from the impact of raindrops. In the intershrub spaces, sheet rill removes litter from the soil surface. Overall, these soils are low in nitrogen (Table 2); however, what little nitrogen is present is distributed heterogeneously. Soils under the canopies of the shrubs are considered "islands of fertility" (Garcia-Moya and McKell 1970); intershrub spaces are nutrient poor and seldom colonized, even by annuals, and tend to remain bare even in wet years (Table 1) (also see Cornelius and Cunningham, this volume).

Alluvial Fan Apron. Longitudinal gradients of the watershed continue to decrease away from the mountain front and as elevation approaches the watershed base level. Eventually, a point is reached where the slope is insufficient for runoff to maintain distinct channels. Instead each channel gives way to a braided network which eventually disintegrates as runoff begins to move as sheet flow.

Within this transitional zone runoff rapidly decreases in energy as it spreads laterally across the watershed. Correspondingly, most of the bedload, and the coarser fraction of the suspended load, must be deposited (fig. 5), forming the **alluvial fan apron** landform (fig. 4). The coarser texture of the soil surface on the fan apron increases its infiltration capacity and results in a relatively high flow threshold. Therefore, this landform absorbs all runoff originating from the erosional fan remnant in low intensity storms, or from all upslope landforms in greater intensity storms. Sediments and organic matter carried in this runoff are also deposited (fig. 5); coarsest sediments are deposited near the head of the fan apron and progressively finer sediments are carried further down slope with low density organic matter deposited last. When storm intensity exceeds the infiltration capacity, runoff from upslope landforms will be transported across the fan apron.

Larrea tridentata extends from the erosional fan remnant into the fan apron along the braided network of arroyo channels. However, it appears that the deposition of organic matter and the addition of runon water maintain a mixed community of perennial grasses, forbs, and sub-shrubs in the areas between arroyo channels. Also, ephemeral species attain maximal cover (Table 1) and species richness on the fan apron. Since the storm intensities necessary to produce large volumes of runoff from upslope landforms are relatively rare (see Reynolds et al., this volume) there should be a great inter-annual variability in the supply of additional resources. Apparently, these conditions favor the development of a rich ephemeral flora.

Nonburied fan remnant. The watershed below the fan apron, with longitudinal gradients of only 2.1%, is dominated by sheet flow. Here, water movement cannot dissect the surface through gullying or sheet rill as occurs higher on the slope, nor does deposition occur, since the bulk of the sediment load was dropped on the fan apron. Therefore, the original aggradational surface is preserved in a component landform called the **nonburied fan remnant** (fig. 4). However, sheet wash does move some surface sediments during large runoff events. The resulting soil surfaces on both the nonburied fan remnant and the alluvial plain (described below) are similar, so they are discussed together.

Basin Floor

The piedmont slope grades into the **basin floor** - the third major physiographic part - which is an essentially level alluvial or lacustrine plain. This area can be subdivided into two major landforms - **alluvial plain** and **playa** (fig. 4).

Alluvial Plain

The **alluvial plain** is the relictual floodplain of the ancestral Rio Grande River which has not been buried with alluvial sediments, nor eroded. Instead, the soil developed in these fluvial sediments has been preserved relatively intact along the edges of the playa (fig. 4).

Infiltration rates and flow thresholds of the nonburied fan remnant and the alluvial plain are roughly similar to the alluvial fan collar (fig. 5). Therefore, storms of the same intensity exceed the infiltration capacity of all three of these landforms. Runoff originating higher on the watershed during these storms is simply transported across the nonburied fan remnant and alluvial plain into the playa. Both of these landforms support mixed communities of perennial

grasses, forbs and subshrubs, as does the alluvial fan apron, though perennial cover is higher and annual cover is much lower than on the fan apron (Table 1). These transportational landforms are geomorphically stable and disturbance since settlement does not appear to have altered the distribution of resources within this portion of the watershed. Therefore, these areas have maintained a semblance of the primeval desert grassland even without additional organic matter or water supplied through runon.

Playa

The LTER/Jornada watershed lacks an outlet for through flow; therefore, runoff originating on the entire watershed (fig. 3) during rare, high intensity storms occasionally floods the lowest portion of the watershed known as the playa landform (fig. 4). Each flooding event deposits lacustrine sediments, which have accumulated, burying the fluvial sediments of the ancestral Rio Grande River (fig. 5).

This landform is the ultimate sink for nutrients and organic matter within the watershed. The heavy clay soils have the highest nitrogen content (Table 2) and support the highest perennial cover of any landform in the watershed (Table 1).

Conclusions

The preceding section developed a hypothesis demonstrating how distribution of limiting resources may be controlled by geomorphic processes, which would explain the correlation of vegetative communities and landforms on the LTER/Jornada site. However, this hypothesis is site specific. We would now like to develop a general hypothesis, that could include temporal vegetation dynamics at a landscape scale (desertification), and that could apply to a broader region.

GEOMORPHIC PROCESS / VEGETATIONAL MOSAIC MODEL

Drainage basins, the fundamental unit of geomorphology (Chorley 1969), are usually internally drained in the Basin and Range Physiographic Province. Landforms, soils, and vegetation develop simultaneously within these basins under a given suite of environmental and geomorphic conditions. Over 100's of years, the interactive effects of landscape level processes create a metastable state (Forman and Godron 1986, p. 436) which tends to be self-maintaining even under a fairly wide range of exogenous disturbances.

This was the situation in southern New Mexico prior to settlement (Fig. 6). The primeval desert grasslands were a mosaic of vegetation types. The low points of internally drained basins, that were occasionally flooded, but little affected by

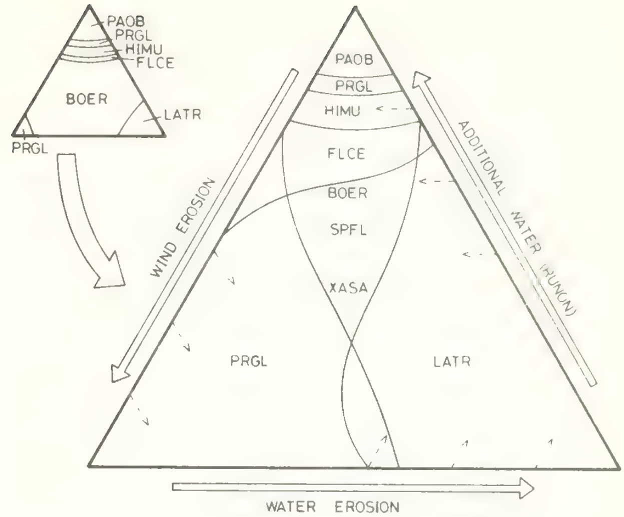


Figure 6. Generalized geomorphic process / vegetational mosaic model. Small triangle in upper left corner represents primeval vegetation mosaic. Large arrow between triangles represents a post-settlement disturbance regime. Large triangle represents current vegetational mosaic. Axes represent increasing levels of wind or water erosion and runon (axes are read parallel to the small dashed arrows). (PAOB - Panicum obtusum; PRGL - Prosopis glandulosa; HIMU - Hilaria mutica; FLCE - Flourensia cernua; LATR - Larrea tridentata; XASA - Xanthocephalum sarothrae; SPFL - Sporobolus flexuosa; and BOER - Bouteloua eriopoda)

wind or water erosion, supported playa communities dominated by the grass Panicum obtusum. These temporary lakes were surrounded by a gallery forest of Prosopis glandulosa, which also bordered major drainage channels. Depositional areas with heavy clay soils and exposed to overland sheet flow (but not holding standing water) were dominated by the grasses Hilaria mutica and Scleropogon brevifolia with occasional Flourensia cernua shrubs. Areas dominated by aeolian erosion, mostly restricted to blow outs along the valley border, were dominated by shrubby forms of Prosopis glandulosa. Areas dominated by fluvial erosion, mostly restricted to mid-piedmont slopes and the tops of small hills and ridges, were dominated by Larrea tridentata. Extensive grasslands, dominated by Bouteloua eriopoda, occupied the remaining area (perhaps as much as 90% of the total surface area)(Buffington and Herbel 1965) and were maintained by relatively homogeneous redistribution of water and vigorous internal cycling of limiting nutrients. These areas included a wide variety of soil types from deep sand to shallow calcareous gravel, and were subject to widely different levels of potential water and wind erosion (Gardner 1951, York and Dick-Peddie 1969, and Stein and Ludwig 1979).

The conversion of these primeval grasslands in southern New Mexico to a heterogenous matrix, dominated by desert shrub species with scattered remnants of the original grassland (fig. 6), has been well documented. The combined effects of several types of disturbance - including drought, overgazing, and trampling - fragmented the once extensive grasslands, forcing the landscape into an unstable state. The rate and extent of erosion, formerly limited by grass cover, increased dramatically (represented by an extension of the two erosion axes in the large triangle, fig. 6). Increased erosion led to increased runoff from some landforms (and increases in runon to other landforms) and eventually to heterogeneous horizontal redistribution of limiting resources within the landscape (represented by an extension of the runon axis, fig. 6).

Changes in the rate or level of the underlying geomorphic processes within the drainage basin led to these heterogeneous patterns of horizontal redistribution of limiting resources. These changes were most likely to occur at the transitions between erosional landforms and stable or aggrading landforms. Using the LTER/Jornada watershed as an example, the transitions between the fan collar (depositional) and the erosional fan remnant or between the erosional fan remnant and the alluvial fan apron (depositional) are most likely to exhibit instability. The current patterns of vegetation communities support this premise.

The lower portion of the fan collar is characterized by a mixture of perennial grasses with abundant subshrubs and is cut by active gullies which indicate accelerated erosion. Though this grassland community does appear degraded, its sharp boundary with the L. tridentata community occurring immediately down slope, indicates that L. tridentata is not extending into this grassland. Geomorphic processes on this degrading grassland appear relatively stable. The grassland is located near the head of the watershed and immediately below the aggradational upper portion of the fan collar which limits the headward cutting channels.

In contrast, the boundary between the erosional fan remnant and the alluvial fan collar (and their associated vegetation communities) is quite gradual. The effects of slightly accelerated erosion upslope of the fan collar become concentrated in the converging drainage network, allowing individual channels to extend down slope, isolating portions of the once depositional surface in their interfluves. Once isolated, these interfluve areas no longer receive additional water or organic matter. Instead they begin to be dissected with sheet rill and colonized by L. tridentata.

The distance that channels can extend down slope is determined by characteristics of the drainage basin, namely the ratio of basin relief to basin length and the catchment size. As the relief:length ratio increases the kinetic energy of runoff increases with a corresponding increase in the effect of water erosion. Similarly, as catchment size increases, a greater volume of runoff can be produced by the watershed, resulting in greater erosion down slope.

The classification of arid rangelands using a hierarchical combination of landforms and the extant vegetation permits the identification of the major processes, such as erosion, deposition, and material redistribution, contributing to vegetation dynamics. There is great potential for this type of dynamic, landscape oriented classification to assist in our attempts to improve management of arid rangelands. For example, it should make it possible to evaluate management decisions in pastures located in upland catchments or in erosional zones of piedmont slopes in light of their probable effects on adjacent landforms. Likewise, this approach will aid in the identification of desertified grassland areas occurring on stable or aggradational landforms that have a high probability for recovery. These are the areas that should receive our greatest efforts and resouces in attempts to reverse desertification trends.

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A Forest Habitat Type Classification of Southern Arizona and Its Relationship to Forests of the Sierra Madre Occidental of Mexico[1]

Esteban H. Muldavin[2] and Robert L DeVelice[3]

Abstract.— A floristic analysis of climax forest communities (habitat types) of southern Arizona reveals that, of the 51 plant associations present, 22 are restricted in the U.S. to the region south of the Mogollon in Arizona and have close floristic affinities to forests of the Sierra Madre Occidental of Mexico. These low elevation forests are characterized by an understory of xerophytic oaks and/or warm season grasses. A case study of a habitat type in Arizona and Mexico indicates that the complexity of forest communities greatly increases in northern Mexico as a function of the proliferation of oak and pine species. This is seen as an aid in developing an habitat type classification in Mexico. An overview of habitat type methodology is presented along with management applications, with an emphasis on timber productivity.

INTRODUCTION

Forest classification systems have been widely developed and used in the western United States to ensure effective forest management. Many of these classifications are based on climax plant associations and have been termed "habitat type" classifications. Land areas capable of supporting a given natural plant association at climax are defined as the same habitat type. Climax vegetation serves as a key to the integrated environment, including climate, soil, and landform conditions as they affect vegetation composition (Daubenmire 1968;1976). A given habitat type represents a relatively narrow range of biotic potential and, thus, a relatively narrow range of management options and improve prediction accuracy for such characteristics as timber and forage production potentials (Layser 1974, Pfister 1976; 1981).

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The forests of the northern Mexico, particularly of the Sierra Madre Occidental, may be ideally suited for the development of a habitat type classification. To evaluate this, we will review the general outline of the habitat type classification of southern Arizona by Muldavin et al. (1987). We will present a floristic analysis of the habitat types, showing the affinities of these communities to the flora of the Sierra Madre Occidental of Mexico. A a case study of how an habitat type of southern Arizona relates directly to those of northern Mexico will also be presented. Finally, we will explore the management applications of habitat type classifications with special reference to coniferous species productivity and make a case for initiating habitat type research in the Sierra Madre of Mexico.

STUDY AREA

In Arizona, the area covered by the habitat type classification of Muldavin et al. (1987) includes most of the mountainous regions south of the Mogollon Rim (Fig. 1). We will be concentrating our analysis on the Southeast Basin and Ranges which lie in a transition zone between the Colorado Plateau and the Sierra Madre Occidental.

In Mexico, our reconnaissance is limited to two areas of the Sierra Madre Occidental (Fig. 2): 1) The Sierra Huachinera which

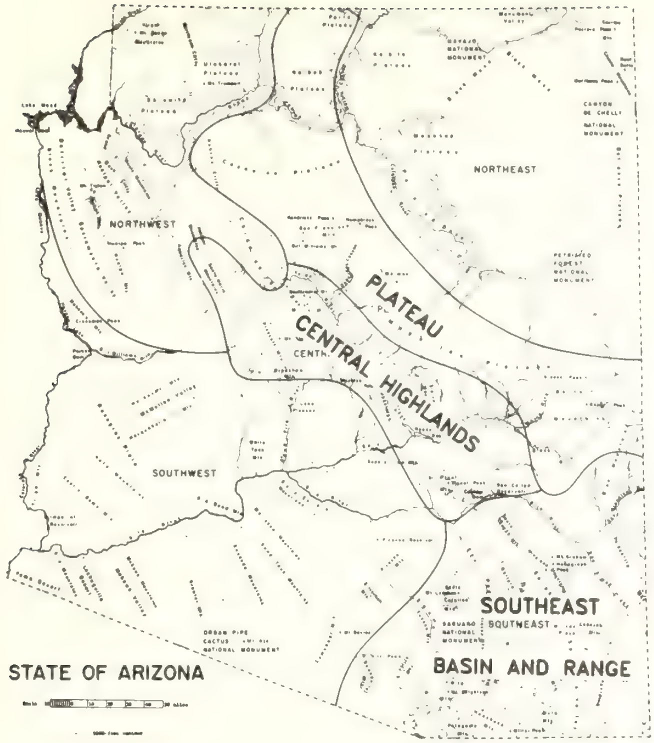

Figure 1.—The study area of Arizona includes the southern edge of the Plateau region, and the mountainous areas of the Central Highlands and Southeast Basin and Range (adapted from Sellers and Hill 1974).

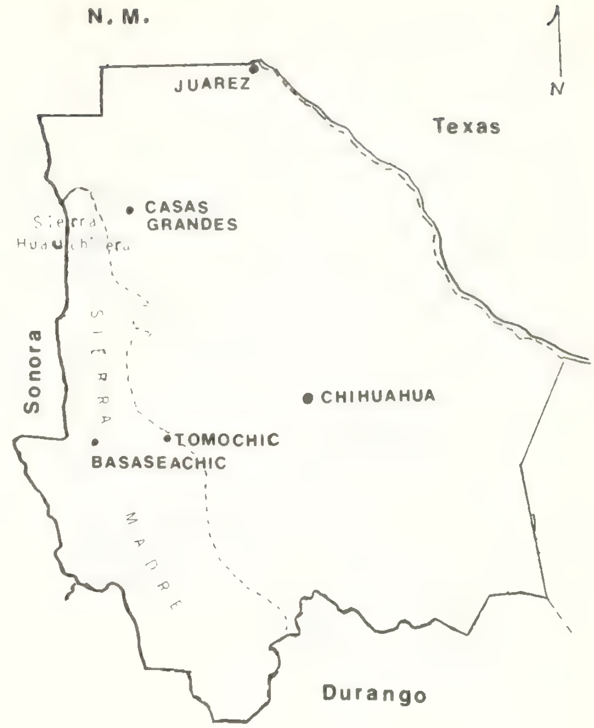

Figure 2.-- The study areas in Chihuahua, Mexico includes the Sierra Huachinera West of Casas Grandes, and the area from Tomochic to Basaseachic (base map from Rzedowski 1978).

straddles the states of Chihuahua and Sonora at the very northern end of the Sierra Madre Occidental, 100 km south of the International Border, and 2) the area from Tomochic to Cascada Basaseachic (due west of Chihuahua City), near the western boundary of Chihuahua with Sonora in the north central Sierra Madre.

METHODS

Forest Habitat Typing

Methods used to develop forest habitat type classifications are basically standardized and have been used throughout the western United States (Pfister and Arno 1980; Moir and Ludwig 1983). Samples are subjectively selected from stands of relatively undisturbed, homogeneous, climax or near climax vegetation. Stands are selected along gradients of altitude, landform, and aspect in an attempt to recover the range of vegetation-environmental variation. The inventory of each sample plot includes density counts of tree species, cover estimation of all shrubs and herbs, recording of site characteristics such as slope, aspect, elevation, landscape position and soil morphology, and the age and height of selected dominant 'site' trees to measure timber productivity.

Plots are subjected to ordination, cluster, and tabular analyses which group plots into plant associations (habitat types) that are defined by the climax tree species (Series), characteristic sets of species (Association), and the environment (Habitat Type). The types are then hierarchically arranged by Series, then Habitat type, and, if defined, Phase. Traditionally, the Series climax species and a characteristic undergrowth species form the basis of habitat type names i.e. the in habitat type name Pinus ponderosa/Quercus hypoleucoides (Greig-Smith 1983; Mueller-Dombois and Ellenberg 1974; Pfister and Arno 1980).

Finally, keys and descriptions for each habitat type are written which include vegetation and site characteristics, and management implications. Although habitat types are defined on sites with climax or near climax vegetation, areas having seral vegetation can usually be identified to habitat type by close examination of site characteristics, adjacent plant associations on the same site (Arno 1982), and by using knowledge of successional trends (Pfister et al. 1977).

Floristic Analysis

The floristic analysis is based on the comprehensive species list for habitat types of

southern Arizona (Muldavin et al. 1987). The species were grouped by geographical affinity into four categories: 1) Petran; species which have the center of their distribution north of the study area along the Rocky Mountain Cordillera into the boreal regions of North America; 2) Madrean; species whose central distribution is south, in the Sierra Madre Occidental of Mexico; 3) Southwest; those species which are regional endemics restricted to the southwest United States, and 4) other species which are either pandemic or show patterns other than those above.

Within each habitat type , the number of species in each category was calculated as a percentage of the total number of species found. Each habitat type was then classified as either predominantly Petran or Madrean.

Sierra Madre Reconnaissance

Ten plots have been established in the northern Sierra Madre Occidental. From these, we have selected three plots of the Pinus leiophylla Series for direct comparison to the similar types in the Southeast Basin and Ranges in Arizona.

RESULTS

Foristics and Ecology of Southern Arizona Habitat Types

The habitat type classification of Muldavin et al. (1987) contains 51 habitat types from eight climax tree series. Floristic analysis of these types (Table 1) indicates that 22 of these types are predominantly Madrean in character. Habitat types of the Engelmann Spruce (Picea engelmannii), Sub-alpine Fir (Abies lasiocarpa), Blue Spruce (Picea pungens) and, White Fir (Abies Concolor) Series lack or have only a minor Madrean floristic component. These are primarily high elevation types of which many are widespread in the Rocky Mountains to the north, but very limited or absent to the south. In the Southeast Basin and Ranges they are found only on the higher mountain tops (Fig. 3).

At lower elevations, the Madrean influence becomes more pronounced. Most of the mid-elevation types of the Douglas-fir (Pseudotsuga menziesii) Series have a strong Madrean component. The majority of the Ponderosa Pine (Pinus ponderosa) Series are dominated by Madrean species. At the lowest elevations, types of the Apache Pine (Pinus engelmannii) and Chihuahua Pine (Pinus leiophylla) Series are overwhelmingly Madrean in floristic composition.

Corresponding with the shift in floristic composition from Petran to Madrean dominance is a major shift in physiognomy of the habitat types. Petran types are dominated by in the

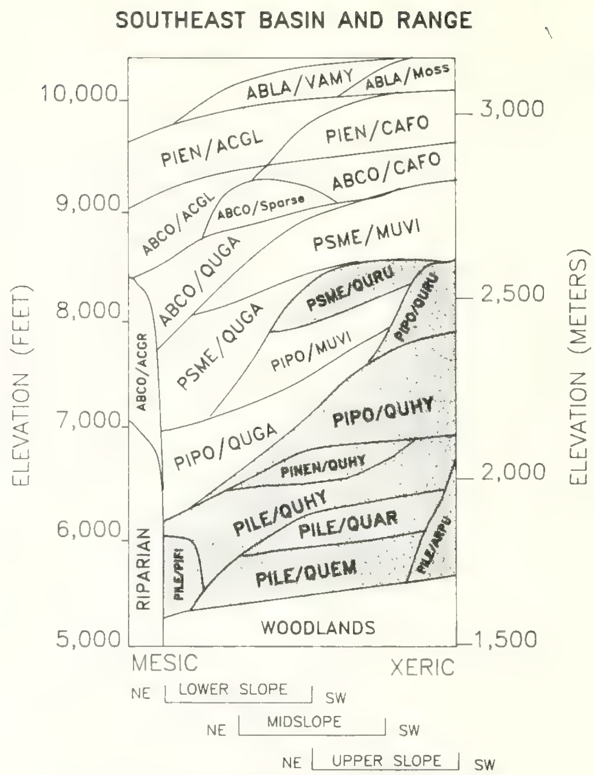

Figure 3.—Schematic illustration of the ecological relationships among the major habitat types in the Southeast Basin and Range region of Arizona. Shaded types are predominantly Madrean floristically. (Adapted from Muldavin et al. 1987)

understory by cool season grasses (Festuca spp, Bromus spp., and Poa spp), mesic cool temperate shrubs (Symphoricarpos spp., Holodiscus dumosa, Vaccinium myrtillus), and a diverse, often luxuriant, herb layer (Erigeron spp, Geranium spp, and Fragaria spp.). In contrast, Madrean types are characterized by an understory of xerophytic oaks (Quercus rugosa, Q. hypoleucoides, Q. arizonica, and Q. emoryi.), warm season grasses (Muhlenbergia longiligula, M. emersleyi, and Piptochaetium fimbriatum) with a herb layer that is sparse and often depauperate in species.

The Madrean types are restricted northward by a combination of cooler temperatures and reduced summer rainfall. The cool to cold temperatures of the Plateau (Fig. 1) exclude most Madrean types despite adequate moisture except in isolated pockets along the eastern edge of the Mogollon Rim. Heavy snow-packs and cool summers favor high montane communities of Rocky Mountain affinity. In the Central Highlands, Madrean habitat types are limited by decreasing summer precipitation and cooler temperatures. The mesic Madrean types such as the Pinus ponderosa/Quercus hypoleucoides (PIPO/QUHY) or the Pinus ponderosa/Quercus rugosa (PIPO/QURU) and those of the Chihuahua and Apache pine Series are absent because of the lack of

Table 1.—Floristic analysis of plant associations/habitat types of southern Arizona. The abreviated code for the association is given along with the full name. Habitat types are ordered by series. The percent composition of each floristic category is given (see text). P=Petran species; M=Madrean species; SW=Southwestern endemics; O=pandemic or other distribution. Source data and habitat type names: Muldavin et al. 1987.

HT CODE	Series/Association/Habitat Type	% COMPOSITION P	M	SW	O
PIEN/Moss	Picea engelmannii/Moss	100	0	0	0
PIEN/CAFO	Picea engelmannii/Carex foenea	85	10	5	0
PIEN/ACGL	Picea engelmannii/Acer glabrum	85	6	3	6
PIEN/EREX	Picea engelmannii/Erigeron eximius	88	6	0	6
ABLA/MOSS	Abies lasiocarpa/Moss	100	0	0	0
ABLA/VAMY	Abies lasiocarpa/Vaccinium myrtillus	96	0	4	0
ABLA/VAMY-RUPA	Abies lasiocarpa/Vaccinium myrtillus-Rubus parviflorus	95	0	5	0
ABLA/RUPA	Abies lasiocarpa/Rubus parviflorus	92	0	4	2
ABLA/EREX	Abies lasiocarpa/Erigeron eximius	94	0	3	3
ABLA/JAAM	Abies lasiocarpa/Jamesia americana	93	0	0	7
PIPU/EREX	Picea pungens/Erigeron eximius	94	0	0	6
PIPU/JUCO	Picea pungens/Juniperus communis	85	6	0	3
PIPU/FEAR	Picea pungens/Festuca arizonica	80	6	6	3
ABCO/VAMY	Abies concolor/Vaccinium myrtillus	85	6	4	14
ABCO/CAFO	Abies concolor/Carex foenea	80	2	4	14
ABCO/ACGL	Abies concolor/Acer glabrum	84	3	5	8
ABCO/Sparse	Abies concolor/Sparse	69	13	3	6
ABCO/QUGA	Abies concolor/Quercus gambelii	83	14	3	3
ABCO/JUMA	Abies concolor/Jugalns major	72	19	3	6
PSME/BRCI	Pseudotsuga menziesii/Bomus ciliatus	81	6	6	7
PSME/MUVI	Pseudotsuga menziesii/Muhlenbergia virescens	46	31	10	13
PSME/MUMO	Pseudotsuga menziesii/Muhlenbergia montana	42	23	23	7
PSME/QUGA	Pseudotsuga menziesii/Quercus gambelii	38	34	14	4
PSME/QURU	Pseudotsuga menziesii/Quercus rugosa	35	40	12	13
PSME/QUHY	Pseudotsuga menziesii/Quercus hypoleucoides	33	42	12	13
PSME/QUAR	Pseudotsuga menziesii/Quercus arizonica	35	44	9	11
PSME/ACGR	Pseudotsuga menziesii/Acer grandidentatum	36	44	9	11
PIPO/FEAR	Pinus ponderosa/Festuca arizonica	63	8	12	17
PIPO/MUVI	Pinus ponderosa/Muhlenbergia virescens	40	37	15	8
PIPO/MUMO	Pinus ponderosa/Muhlenbergia montana	40	25	18	17
PIPO/QUGA	Pinus ponderosa/Quercus gambelii	46	21	21	12
PIPO/BOGR	Pinus ponderosa/Bouteloua gracilis	32	22	16	30
PIPO/QURU	Pinus ponderosa/Quercus rugosa	30	45	13	12
PIPO/QUHY	Pinus ponderosa/Quercus hypoleucoides	24	40	14	22
PIPO/QUAR	Pinus ponderosa/Quercus arizonica	31	35	15	19
PIPO/QUEM	Pinus ponderosa/Quercus emoryi	30	42	10	18
PIPO/ARPU	Pinus ponderosa/Arctostaphylos pungens	33	32	17	16
PIPO/ACGR	Pinus ponderosa/Acer grandidentatum	39	42	13	6
PIPO/JUMA	Pinus ponderosa/Juglans major	33	37	14	16
PINEN/MULO	Pinus engelmannii/Muhlenbergia longiligula	33	47	17	3
PINEN/QURU	Pinus engelmannii/Quercus rugosa	12	75	12	0
PINEN/QUHY	Pinus engelmannii/Quercus hypoleucoiudes	27	53	12	8
PINEN/QUAR	Pinus engelmannii/Quercus arizonica	10	70	13	7
PINEN/QUEM	Pinus engelmannii/Quercus emoryi	6	78	6	10
PILE/QUHY	Pinus leiophylla/Quercus hypoleucoides	15	66	10	9
PILE/QUAR	Pinus leiophylla/Quercus arizonica	17	64	13	6
PILE/QUEM	Pinus leiophylla/Quercus emoryi	16	64	12	8
PILE/PIFI	Pinus leiophylla/Piptochaetium fimbriatum	12	71	8	9
PILE/ARPU	Pinus leiophylla/Arctostaphylos pungens	23	46	19	12
PILE/QUTO	Pinus leiophylla/Quercus toumeyi	0	89	5	6

adequate summer moisture at sufficiently long and warm growing seasons. Instead, the more xeric Pinus ponderosa/Quercus arizonica and Pinus ponderosa/Quercus emoryi types are found at low elevations, and the Pinus ponderosa/Quercus gambelii and Pseudotsuga menziesii/Q. gambelii types at the cooler, higher elevations. The highest diversity of Madrean types in the United States occurs in the Southeast Basin and Ranges region (Fig. 3) where temperatures are milder and summer precipitation greater. This region as a whole represents a highly diverse transition zone between the Sierra and Rocky Mountain Cordilleran vegetation.

Habitat Types in Southern Arizona and Mexico: A Case Study.

The low elevation habitat types of the Southeast Basin and Range region of Arizona are northern extensions or modified phases of communities that are more common in the northern Sierra Madre Occidental of Mexico. As an example, we will use the Pinus engelmannii/Quercus hypoleucoides Habitat Type (PINEN/QUHY HT) and briefly examine how this type is expressed in southern Arizona, the Sierra Huachinera, and at Cascada Basaseachic. The foregoing discussion is based on a limited, initial field reconnaissance in Mexico, but through it some of the continuities and discontinuities between northern Mexico and southern Arizona can be illustrated.

Figure 4 depicts a typical stand of PINEN/QUHY found at about 2,150 M in southeast Arizona. The type is characterized by an open canopy of mature Apache pine (Pinus engelmannii) with ample seedlings and saplings below. Chihuahua pine (Pinus leiophylla) is often a sub-dominant associate along with alligator bark juniper (Juniperus deppeana). The undergrowth is dominated by shrubby silver-leaf oak (Quercus hypoleucoides) with cover ranging as high as 80%. Other oaks such as net-leaf (Q. rugosa), Arizona white (Q. arizonica), and Emory (Q. emoryi) may be present but their cover is usually low (less than 5%). The herb layer is low in cover and diversity, and dominated by long tongue muhly grass (Muhlenbergia longiligula). This is one of the more mesic of the Madrean types occupying the mid and upper slopes at mid elevations in southeast Arizona (Fig. 3).

In the Sierra Huachinera, this type is found with essentially the same composition and site conditions (Fig. 5). Apache pine is the overstory dominant, but Arizona pine (Pinus arizonica) in this case is the sub-dominant rather than Chihuahua pine. Silver-leaf oak still dominates the understory along with long-tongue muhly. It is in the Sierra Huachinera, though, that the proliferation of xerophytic oak species begins and increases as you go south into the central Sierra Madre. For example, it is possible in the Sierra Huachinera to have

Figure 4.—A typical stand of the Apache pine/silverleaf oak habitat type in the Chiricahua Mountains of southeast Arizona.

Figure 5.—A stand of the Apach pine/silverleaf oak in the Sierra Huachinera of northern Mexico.

Q. crassifolia, a close relative of Quercus hypoleucoides (with which it hybridizes), in a stand of PINEN/QUHY. The situation becomes more complex the further south one goes as more oaks and new pines are encountered which are not present in Arizona.

Another 200 km further south, west of Tomochic toward Basaseachic we recorded fragments of the PINEN/QUHY habitat type, but here the type is immersed in a complex mosaic of other habitat types that have yet to be described in detail. Figure 6 shows what is best described as the Pinus engelmannii/Quercus crassifolia Habitat Type. Apache pine is still the dominant with ample reproduction. Chihuahua pine is the subdominant. But silver-leaf oak is absent and Q. crassifolia dominates with about 25% cover. Arizona white oak is less than 2% cover and Emory oak has been replaced by Q. coccolobifolia, (a relative of Emory oak).

The site at Cascada Basaseachic was sampled to exemplify the increasing complexity of forest communities in the Sierra Madre of Mexico relative to those in southern Arizona. In Figure 7, Apache pine still dominates the overstory, but in association with a new pine, P. lumholtzii, as well P. arizonica. Silver-leaf is still present but Q. crassifolia domininates along with Q. coccolobifolia, Q. durifolia, Q. rugosa, Q. arizonica, and Q. sideroxyla. Longtongue muhly is still the understory dominant, but there is a higher overall diversity with a entire suite of species that are present here, but not in southern Arizona.

This diversity at first appears bewildering and an impediment to classification. But to the contrary, the forests of the Sierra Madre Occidental are ideally suited for habitat typing because the increased diversity in plant assemblages may help provide the information necessary to differentiate some of the finer aspects of the environment.

MANAGEMENT APPLICATIONS

Habitat classifications have been put to use in many natural resource management areas such as assessing range capacity, wildlife habitat needs, recreation use impact, pest management problems, as well as timber productivity. But the primary focus in the U.S. has been toward timber. Daubenmire (1976) laid the theoretical groundwork for the application of vegetation classification in assessing productivity. Mathiasen et al. (1986) have shown significant differences for Douglas-fir among different habitat types. Muldavin et al. (1987) have shown similar trends for Ponderosa pine. There is little or no silvicultural or productivity data available on Chihuahua pine or Apache pine in the U.S. Here we present some preliminary data on Chihuahua pine growth that shows some trends in the relationship of productivity to habitat type.

Figure 6.—To the west of Tomochic, Mexico, this stand is dominated by Apache pine, but with Quercus crassifolia and Q. cocolobifolia in the understory rather than Quercus hypoleucoides (silverleaf oak).

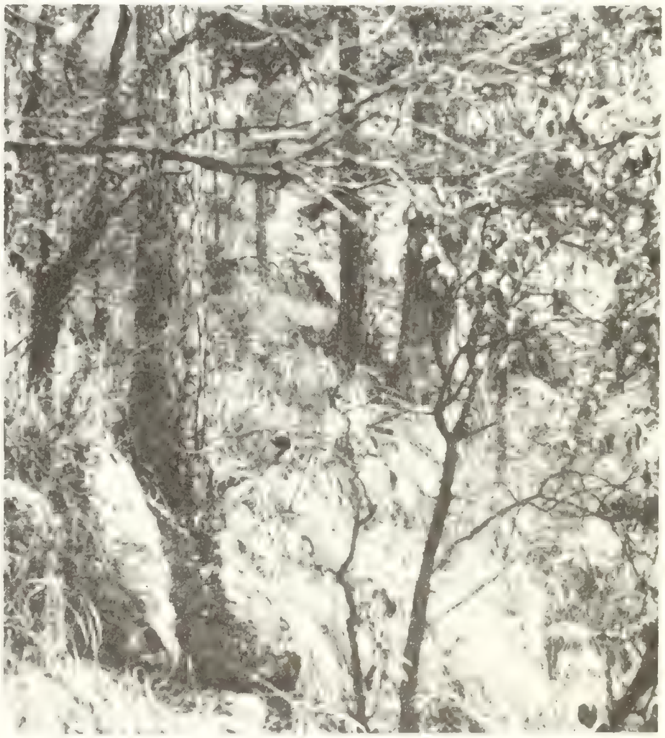

Figure 7.—At Cascada Basaseachic, this Apache pine community is dominated by numerous other oaks besides silverleaf. Note the high cover of longtongue muhly grass in this ungrazed site.

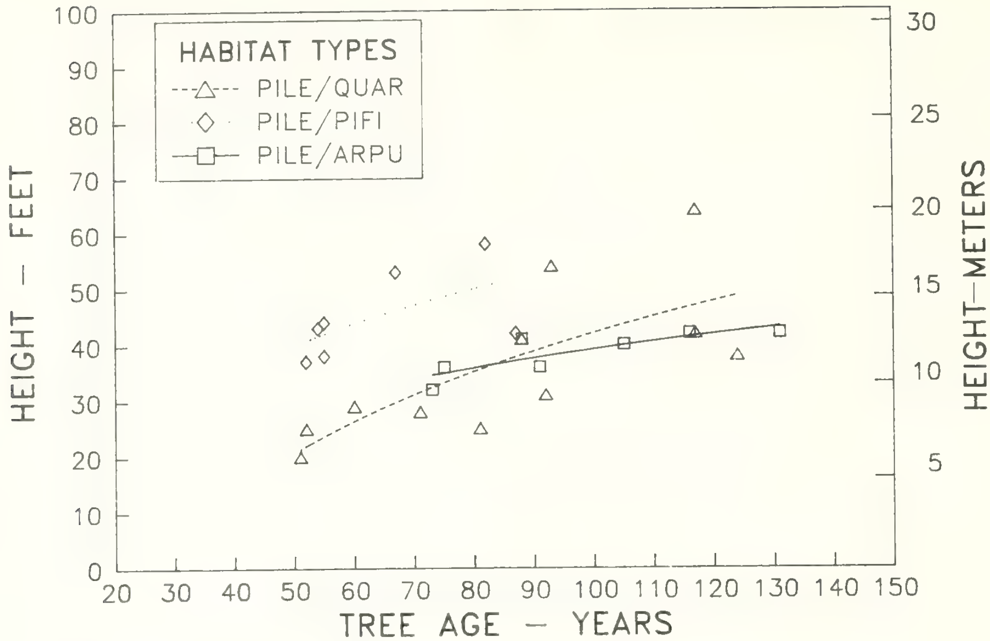

Figure 8.—A comparison of height vs. age relationships for Chihuahua pine (Pinus leiophylla) among three different habitat types. Refer to Table 1 for the definition of the type codes.

Chihuahua pine is a short lived tree which, in Arizona, is of relatively short stature (less than 20 m). Figure 8 depicts the differences in growth among three habitat types of the Chihuahua pine series. A logarithmic regression was applied to the points of each habitat type to give an initial approximation of the general trends of growth. The Pinus leiophylla/Piptochaetium fimbriatum habitat type (PILE/PIFI HT), which is found on well watered, lower slopes and alluvial terraces, shows the highest rate of growth, reaching near the potential of the species within 80 years. In the P. leiophylla/Quercus arizonica type (PILE/QUAR HT), growth is slower and the potential of species is probably not normally reached until after 100 years. This lowered productivity corresponds to the drier mid to upper slope position of the type. The P. leiophylla/Arctostaphylos type (PILE/ARPU HT) is found on ridge and mesa tops with lithic soils and is the most xeric of the types shown. Chihuahua pine seldomly exceeds 12 m in this community and never reaches the potential of the species regardless of age.

This data is based on field determinations of age and height with limited precision instrumentation. We believe, that with greater precision, that the fit of these curves would be considerably better and that future, intensive analysis will better show the strong correlations between site productivity of Chihuahua pine and habitat type.

SUMMARY and CONCLUSIONS.

Forest habitat type classifications have a relatively long history of development and application in the western United States. Mexico has yet to implement a high resolution system of classification for its vegetation resources. It is the authors' belief that such classifications could be produced using standardized techniques developed in the western United States. We have shown here that many of the habitat types described for southern Arizona by Muldavin et al. (1987) are related floristically to the forests of the Sierra Madre Occidental of northern Mexico. A case study of the Pinus engelmannii/Quercus hypoleucoides Habitat Type (Chihuahua pine/silver-leaf oak HT) indicates that this type can be found not only in southern Arizona, but at least 300 km south in the north central Sierra Madre. But the forests of the Sierra Madre are more diverse as a function of the proliferation of oak and pine species which are not found in southern Arizona, and as a consequence form a complex mosaic of communities. This increased diversity may be an aid rather than a hindrance in delineating a forest community classification for Mexico by embodying the ecological information necessary to differentiate finer aspects of the environment.

A forest classification of the Sierra Madre would provide an ecologically based, high resolution, land management tool for assessing range potential, wildlife needs, recreation impact,

pest hazards, and in particular forest tree productivity. We have shown here, general differences in site productivity for Chihuahua pine as a function of habitat type. With a high precision methodology to determine the age and height relationships, a habitat type classification can be a good predictor of site productivity.

Forest habitat typing in Mexico represents a new frontier not only in the science of vegetation ecology but also in the application of ecological principles in management of this valuable resource for the future well being of the citizens of Mexico.

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A Research Strategy for Ecological Survey: Floristics and Land Use in the Tamaulipan Thornscrub, North-Eastern Mexico[1]

Nick Reid, Mark Stafford Smith, Peter Beyer-Münzell, and Jorge Marroquín[2]

Abstract.--A research strategy was developed to identify the ecological effects of management and the physical environment in the subtropical, semi-arid thornscrub of north-eastern Mexico. Classification and ordination analyses of vegetation samples stratified across a small number of climatic sub-regions, substrate types and topographic situations suggested that these variables were responsible for the major floristic differences. The distribution of most plant species was related to the variation in the physical environment. Ordination of samples in each major floristic group revealed evidence of vegetation change due to overgrazing but not to selective cutting of timber and firewood.

INTRODUCTION

The Tamaulipan thornscrub is a diverse, dense, woody formation covering about 125,000 km^2 of the Gulf coastal plain in north-eastern Mexico and southern Texas (Johnston 1963; Udvardy 1975). Heiseke & Foroughbakhch (1985) reported that uncontrolled grazing and wood extraction may have degraded thornscrub productivity in the region of Linares, Nuevo León. Silvicultural and agroforestry practices offer a solution for preventing further degradation of the natural vegetation and for increasing forage and wood production (Foroughbakhch & Peñaloza 1987; Foroughbakhch et al. 1987, this volume). However, extrapolation of the site-specific results of agroforestry research is difficult because a number of ecological factors vary across the region. The separate effects of climate, substrates, topography and management need to be distinguished in order to identify the sites where silvicultural and range research might be relevant.

The present study was initiated in order to identify the major ecological determinants of the floristic variation in the Tamaulipan thornscrub. A sampling and analytical strategy incorporating the multivariate methods of Foran et al. (1986) was developed to assess the separate effects of physical environmental variables and management on vegetation. In this paper, we (1) test the assumption that climate, substrate and topography are the principal factors associated with floristic variation in the regional vegetation; (2) relate variation in each of the physical environmental variables to floristic differences in the vegetation; and (3) seek relationships between vegetation and management within each major floristic group.

METHODS

Study Area

Fieldwork was conducted within a 20 km radius of Linares, N.L. in the piedmont of

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[1]Paper presented at the symposium "Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones" (Tucson, Arizona, October 12-16, 1987).

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the Sierra Madre Oriental (fig. 1). The region has a subtropical semiarid climate, with hot humid summers and severe frosts in winter (Norwine 1978; Synnott 1986). A strong climatic gradient prevails across the region, due to the orographic effect of the Sierra and the gradual increase in elevation from east to west. Conditions are relatively cool and humid south-west of Linares, grading to warm and dry to the north-east (fig. 1; SPP 1981a). The principal landforms are plains and gentle slopes, interspersed with ridges and hills up to 50 m higher than the surrounding terrain. Soils of the plains and lower slopes are dark grey silty-clay vertisols. On gentle hills and upper slopes, outcrops of Upper Cretaceous lutita (lutite or siltstone) occur, often overlain by silty-clay-loams. Scattered Pliocene and Quaternary palaeoriver terraces of conglomerate, often consolidated in a limestone (caliche) matrix, are found throughout the region. Caliche terraces usually cap ridges and rises or occur as raised benches because they are more resistant to weathering than the lutita bedrock[3].

The native vegetation is a spiny scrub dominated by woody plants (Heiseke 1986). Some 80 shrubs and trees varying in height from 1 to 8 m are commonly encountered. The rural population exploit the thornscrub for a wide variety of purposes (Heiseke & Foroughbakhch 1985). The most extensive land-use is the rough grazing of cattle and goats. The natural vegetation also provides firewood, fenceposts and construction timber, foodstuffs, herbs and natural medicines. Wildfire is unknown in the thornscrub near Linares and human burning of the natural vegetation is rare, so the present vegetation has developed in the absence of fire.

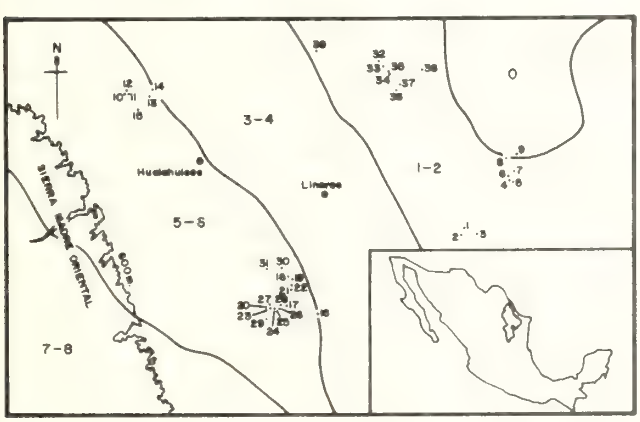

Figure 1.--Location of sites in the region of Linares, N.L., north-eastern Mexico. Sites were sampled in two climatic subregions of the SPP (1981b) Map of Soil Moisture (based on Thornwaite's soil water store index). The dry and humid subregions correspond to 1-2 and 5-6 months of the year with sufficient soil moisture to permit plant growth, respectively.

Research Philosophy

Climate, substrate and topography determine the potential for vegetation development in any one site near Linares. We selected two climatic subregions, three substrate types and three topographic situations which preliminary observations indicated were responsible for the major differences in vegetation between sites. A dry and a humid subregion were delimited towards either end of the regional climatic gradient (fig. 1). Substrate types were (1) deep soils (>50 cm in depth), (2) skeletal soils (<50 cm in depth) over caliche, and (3) skeletal soils over lutita. The topographic situations were (1) upper slopes, (2) level sites and (3) depressions, chosen for their different effects on run-off and the soil moisture store.

Given sufficient time free from interference by man, two sites with the same combination of climate, substrate and topography (i.e. in the same environmental unit) will share a similar floristic composition. However, such sites can support very different vegetation owing to varying management influences such as grazing and cutting.

To summarize then, we expected that most floristic variation between environmental units would be related to the major differences in the physical environment, and that management effects would be most easily detected in environmentally homogeneous groups of sites.

Survey Methods and Analysis

We sampled 39 sites, 0.5 ha in area, stratified across nine environmental units (table 1). At each site, the slope was measured and soils data were recorded from 3 to 5 pits, 20 to 40 cm deep. Where the substrate permitted, a soil core was extracted from each pit to a depth of 1 m in order to measure soil depth.

A list of the woody and large succulent plants was compiled at each site. Plant cover was measured in open vegetation by estimating the canopy area of plants along a transect. In dense vegetation, cover was measured using the point interception method. A site cutting index was calculated by counting all the cut stems, branches and stems $\geq$ 3 cm in diameter. In order to assess grazing pressure, we counted the dung of large (cattle and horses), medium (goats and deer) and small (rabbits and hares) herbivores, and rated the degree of browsing damage to woody plants (Reid et al. 1987). A site browsing index was calculated as the mean of the browsing damage index of each species.

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[3] Ruíz, Miguel. In prep. Soils and landforms in the region of Linares, N.L. México. Ph.D. Thesis. U. of Göttingen, F.R.G.

We used the classification and ordination programs in the TAXON package of programs developed by the CSIRO Division of Computing Research (Ross et al. 1983).

RESULTS

Main Floristic Groups

The initial classification sorted the 39 sites into four groups of sufficient size for further analysis (fig. 2). The initial split in the dendogram separated the 8 dry caliche sites (group A) from the rest. The second division separated the remaining 9 dry sites (all with deep soils; group B) from the humid sites. The third division separated 12 sites with mainly deep soils (group C) from 10 sites with mainly skeletal soils (group D). Thus the main divisions in the classification analysis corresponded with climate and substrate type (table 1).

Two sites on caliche slopes (25 & 30) were floristically classified with humid, deep soil sites in group C, and three deep soil sites (21, 27 & 28) were grouped in the humid, skeletal soil group D (table 1). Sites 27 and 28 had deep silty-clay-loam soils and showed more floristic affinity with skeletal soil sites than with the silty-clay vertisol sites of group C. Sites 25 and 30 lacked most of the character species of either humid group and site 30, at least, had more soil overlying the hardpan than other caliche sites. Site 21 had a substrate typical of the vertisol sites of group C but lacked a majority of the character species of either humid floristic group.

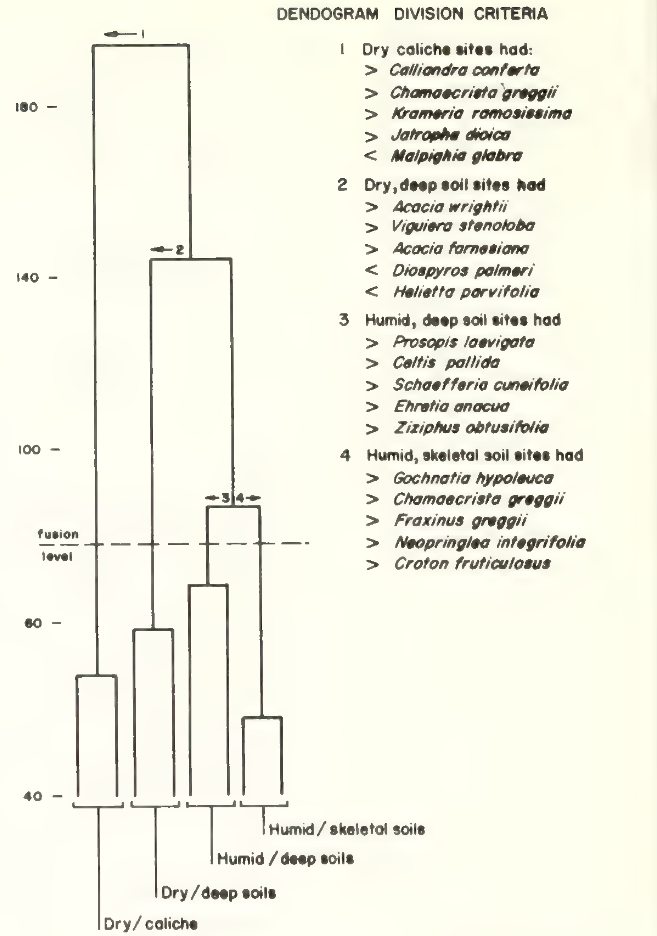

Figure 2.--Dendogram of the classification of sites after application of the Information Statistic to the species-site matrix of incidence data.

Table 1.--Stratification of sites across environmental units, and classification of floristic groups using the Information Statistic with incidence data.

Environmental Units: Climate	Substrate	Topography	No. of sites	Classification of sites	Floristic group
Dry	Caliche	Slope	4	1 3 9 39	A
Dry	Caliche	Level	4	2 8 32 33	
Dry	Deep soil	Level	6	4 5 6 34 35 36	B
Dry	Deep soil	Depression	3	7 37 38	
Humid	Deep soil	Slope	1	10	C
Humid	Deep soil	Depression	4	12 14 22 23	
Humid	Deep soil	Level	8	16 17 18 19 26 / 21 27 28	
Humid	Caliche	Slope	5	25 30 / 13 15 31	
Humid	Lutita	Slope	4	11 20 24 29	D

In the ordination of the species-site data, the first three vectors accounted for 18, 16 and 8%, respectively, of the variance. Sites were grouped into their a priori defined environmental units and plotted against vectors 1 to 3 in figures 3 and 4. Correlations between site loadings and physical environmental variables masked out of the ordination showed that the first vector ordinated sites along a combined substrate-topography axis, with caliche and upper slope sites at one extreme ($P < 0.001$) and deep soil sites and depressions at the other ($P < 0.001$). The second vector represented a simple climatic gradient between dry and humid sites ($P < 0.001$), upper slopes ($P < 0.05$) and lutita sites ($P < 0.01$) clustering at the humid end of the gradient. The third vector was correlated with topography, with level sites ($P < 0.01$) at one extreme and depressions ($P < 0.001$) at the other. Thus the first three floristic vectors were related to climate, substrate or topography (table 2).

The four major floristic groups separated out in the plots of the first three vectors (figs 3 & 4) with the exception of site 21, which overlapped with the humid, deep soil group C, although classified in the humid, skeletal soil group D.

Relationships between plant species and environment

Of the 78 taxa of woody and large succulent plants recorded in the study, 44% showed significant deviations from random occurrence among floristic groups. Table 2 lists the species, the floristic groups which they characterize and the environmental associations of each group.

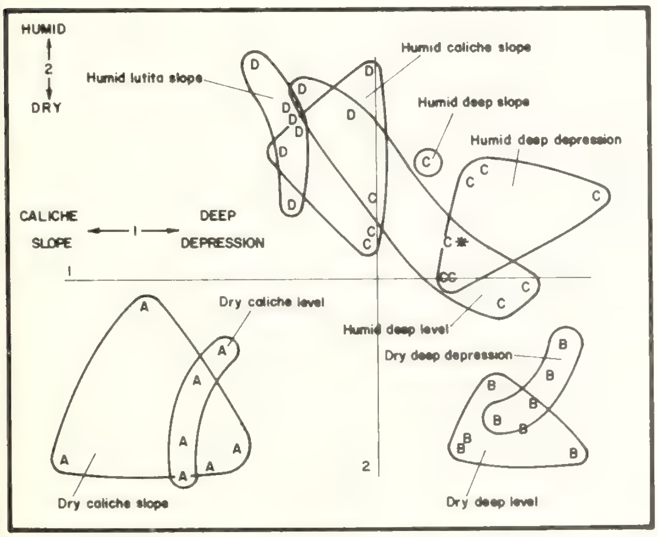

Figure 3.--Ordination of sites against vectors 1 and 2 after application of the Information Statistic to the species-site matrix of incidence data. The letters A to D refer to the floristic groups. The star represents site 21.

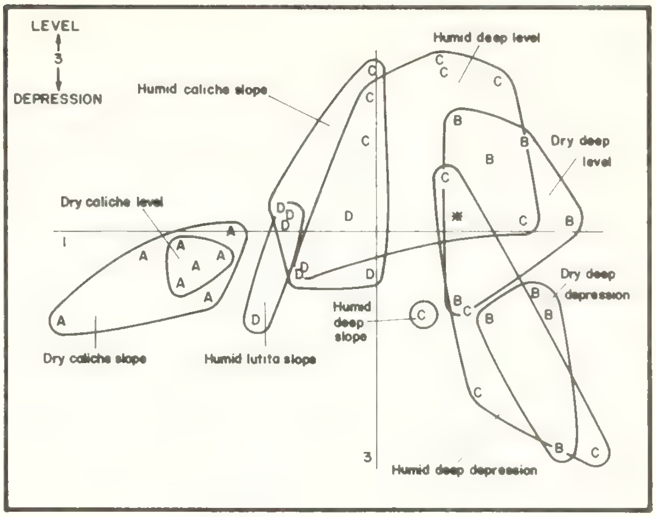

Figure 4.--Ordination of sites against vectors 1 and 3 after application of the Information Statistic to the species-site incidence data. The letters A to D refer to the floristic groups defined by classification analysis. The star represents site 21.

Table 2 also shows the taxa correlated with the first three ordination vectors. 72% of taxa were correlated with one or more vectors. The first vector separated species characteristic of the caliche dominated groups (A & D) such as Chamaecrista greggii and Helietta parvifolia, from species of deep soils such as Celtis pallida and Zanthoxylum fagara. Vector 2 identified a group of humid dwelling species such as Diospyros palmeri and Randia spp., including those typical of shallow soils on upper slopes (e.g. Fraxinus greggii and Gochnatia hypoleuca). At the other extreme were species frequent on dry level sites such as Opuntia leptocaulis and Porlieria angustifolia. Correlations with the third vector separated taxa characteristic of depressions (e.g. Parkinsonia aculeata and Ehretia anacua) from those more frequent on level sites (Castela texana and Amyris madrensis).

Management effects

For each floristic group in turn, the Bray-Curtis metric of dissimilarity was applied to the plant cover data followed by ordination of the sites using Principal Coordinates Analysis (PCoA). The first three vectors of the ordinations of groups A to D accounted for 65, 63, 61 and 57% of the cumulative variance, respectively. Table 3 shows the correlations between the principal vectors of each ordination and the site attributes masked out of the analyses.

The browsing index was marginally or significantly correlated with vectors in each ordination, and negatively correlated with woody understorey cover in each floristic

Table 2.--Relationships between plant species and environmental variables. Associations of species and environmental variables with floristic groups (two-tailed X^2 tests, $P \leq 0.05$) are shown in columns A to D. Correlations ($P \leq 0.05$) of ordination vectors with species and environmental variables are positive (+) or negative (-).

		Floristic Group				Vector		
		A	B	C	D	1	2	3
ENVIRONMENTAL CORRELATES								
Climate	Humid			+	+		+	
	Dry	+	+				-	
Substrate	Deep		+	+		+		
	Caliche	+			+	-		
	Lutita				+		+	
Topography	Slope	+			+	-	+	
	Level	+	+	+				+
	Depression		+	+		+		-
SPECIES								
Acacia berlandieri							-	+
Acacia constricta		+				-	-	
Acacia farnesiana			+			+		-
Acacia schnafferi								+
Acacia wrightii			+			+	-	
Agave lechuguilla						-		
Amyris madrensis								+
Amyris texana			+	+	+	+	+	+
Berberis chochoco				+	+		+	
Bernardia myricaefolia							+	+
Bumelia celastrina			+	+	+	+	+	
Caesalpinia atropunctata						+		
Calliandra conferta		+				-	-	
Calliandra eriophylla						-		
Chamaecrista greggii		+			+	-		
Castela texana			+	+		+		+
Celtis laevigata								-
Celtis pallida			+	+		+		
Citharexylum berlandieri				+	+		+	+
Condalia hookeri			+	+	+	+	+	
Croton fruticulosus		+		+	+	-		+
Diospyros texana						+	+	
Diospyros palmeri				+	+		+	
Ehretia anacua						+		-
Eysenhardtia polystachya		+		+	+	-		
Forestiera angustifolia			+	+	+	+	+	
Forestiera racemosa								-
Fraxinus greggii					+		+	
Gochnatia hypoleuca					+		+	
Helietta parvifolia		+		+	+	-	+	
Heliotropium calcicola							+	
Heliotropium torreyi						-	-	
Jatropha dioica		+				-	-	
Krameria ramosissima		+				-	-	
Leucophyllum frutescens						-		
Malpighia glabra			+	+	+	+	+	
Morus microphylla								-
Neopringlea integrifolia					+	-	+	
Opuntia lindheimeri						-		
Opuntia leptocaulis		+	+	+			-	+
Parkinsonia aculeata						+		-
Pistacia texana							+	-
Pithecellobium ebano			+	+		+		
Pithecellobium pallens			+	+	+	+	+	
Porlieria angustifolia							-	+
Prosopis laevigata			+	+		+	-	
Randia spp			+	+	+	+	+	
Rhus pachyrrachis					+		+	
Sapindus saponaria								-
Sargentia greggii								-
Schaefferia cuneifolia							-	+
Viguiera stenoloba			+			+	-	
Xylosma flexuosa				+	+		+	
Yucca filifera						-		+
Zanthoxylum fagara			+	+	+	+	+	
Ziziphus obtusifolia			+	+		+	-	+
Unknown taxon			+			+		-

group (r_p varied between -0.49 and -0.65, $0.08 \leq P \leq 0.27$). In dry, deep soil sites, browsing index and quantity of large herbivore dung were positively correlated with the cover of the toxic shrub, *Karwinksia humboldtiana* ($P<0.01$), and the spiny succulent, *Opuntia leptocaulis* ($P<0.01$), and browsing index was correlated with the cover of the leathery-leaved *Cordia boissieri* ($P<0.05$). Large herbivore dung was also positively correlated with *O. leptocaulis* cover in dry caliche sites ($P<0.01$). In the eight humid, deep soil sites, browsing index and the quantity of large herbivore dung were negatively correlated with the cover of the forage shrub, *Amyris texana* ($r_p = -0.89$ and -0.68, $P<0.01$ and $P=0.06$, respectively). In the same sites, quantity of large herbivore dung was negatively correlated with both total woody cover and understorey cover ($P<0.05$).

The number of cut stems was significantly correlated with the first vector in the ordinations of the dry caliche and the humid, skeletal soil groups (table 3). In dry caliche sites, the number of cut stems was correlated with upperstorey cover ($P<0.001$) and height ($P<0.05$) of the vegetation. Cut stems were positively correlated with the cover of the important timber and firewood species such as *Helietta parvifolia*, *Gochnatia hypoleuca* and *Cordia boissieri* ($P \leq 0.05$) in the skeletal soils group, and with the cover of *Condalia hookeri* ($P<0.01$) in the humid, deep soil sites.

DISCUSSION

The use of multivariate and correlation analyses has important implications for both the interpretation of results and research strategy. Multivariate statistical techniques such as the Principal Coordinates Analyses described above are based on restrictive mathematical models which may be inconsistent with the ecological behaviour of plants (Gauch 1982; Austin 1985), and correlations between variables do not permit the inference of cause or effect. Moreover, linear correlations between explanatory variables and floristic ordination vectors may overlook significant pattern because linear ordination techniques tend to distort non-linear plant response curves in two or more dimensions (Austin 1985). Therefore, multivariate and correlation analyses cannot provide conclusive evidence of causal relationships between vegetation and ecological variables (Gauch 1982), but they are useful in generating hypotheses about floristic variation and its ecological determinants (Foran et al. 1986). Research strategies for ecological inventory which incorporate multivariate analysis should therefore conform to an iterative cycle of (1) field data collection, (2) analysis and hypothesis generation, and (3) further field work and experimentation to test the hypotheses

Table 3.--Correlations of principal vectors with management variables and descriptors of vegetation structure masked out of the Bray-Curtis ordinations of each floristic group. +/- indicate the sign of the correlation. Degrees of freedom vary between 5 and 7. $P<0.1$ unless otherwise indicated.

Vector	A Dry Caliche (8)	B Dry Deep (9)	C[1] Humid Level (3)	D[2] Humid Skeletal (9)
1	+ cut stems** + veg. height* + upperstorey cover**	+ upperstorey cover*	+ upperstorey cover* - understorey cover*	- cut stems**
2	+ medium herb. dung** - large herb. dung	+ browse index + small herb. dung*** - understorey cover* - veg. height**	- browse index + veg. height**	
3	+ browse index* - understorey cover			- browse index*** - large herb. dung + understorey cover

Floristic Groups (No. of sites)

[1]Bray-Curtis ordination of the original 12 sites revealed considerable variance due to substrate and topographic differences between sites. The dataset was therefore modified to comprise eight humid, deep soil sites by eliminating depression and caliche sites and by inclusion of sites 21 and 28.

[2]Site 21 was not included in the ordination because of its environmental and floristic affinity with group C sites (figs 2 & 3; table 1).

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

generated by analysis. The fieldwork, analysis and hypotheses described in the present paper represent the first step in this process.

We hypothesized that physical environmental variables were the principal factors associated with floristic variation in the region. To the extent that climate, substrate and topography were significantly correlated with each division in the classification analysis and the three principal ordination vectors, that hypothesis was upheld.

The classification of humid sites 27, 28 and 30 underscored the importance of subtle variation in soil texture and depth, and indicated that some of the *a priori* defined substrate and topographic types encompassed major floristic variation. To minimize floristic variation within environmental units in future work, substrate type (1) could be replaced by (1) silty-clay vertisol (> 50 cm depth), and topographic type (2) should be changed to (2) level site on a plain or flat (*sensu* McDonald et al. 1984). Site 25 lacked character species of either humid group, and therefore could have been classified in groups C or D. Site 21 was seemingly misclassified, considering its environmental characteristics and its association with group C sites in ordination (figs 3 & 4). In these cases, environmental unit affiliation may be a better guide to floristic composition than the Information Statistic classification procedure.

Table 2 summarizes the proposed relationships between the distribution of plant species and climate, substrate and topography. These hypotheses require testing in further fieldwork and experiments.

The Bray-Curtis ordinations revealed evidence of grazing effects on vegetation composition and structure, although the sample sizes were small and probability levels were sometimes marginal. Large herbivore (principally cattle) browsing was

associated with a reduction in woody understorey across the region. The highly preferred forage undershrub, Amyris texana (Reid et al. 1987), was less abundant in heavily grazed humid sites, and toxic, spiny and unpalatable species such as Karwinksia humboldtiana, Opuntia leptocaulis and Cordia boissieri (Reid et al. 1987) were more abundant in heavily grazed areas in the dry zone. Thus grazing may have caused a variety of undesirable vegetation changes in both climatic zones.

Wood cutting, on the other hand, was not linked to deleterious vegetation change. The number of cut stems was positively related to the abundance of the valuable timber and firewood trees, rather than the reverse. In several sites, however, we observed that stumps of the heavily exploited Condalia hookeri had not resprouted after the removal of all stems. Further study of the ability of C. hookeri to survive cutting in different environments and its abundance in relation to cutting intensity is desirable.

ACKNOWLEDGMENT

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MODELO PARA PREDECIR PRODUCCION DE HOJA DE OREGANO (*LIPPIA BERLANDIERI*) EN POBLACIONES NATURALES EN JALISCO, MEXICO[1]

J. Rafael Cavazos Doria[2]

Resumen.--En éste estudio se evaluaron algunos factores ambientales que afectan la producción de orégano (Lippia berlandieri). Se encontró que el mejor modelo estadístico para predecir peso de hoja seca fué usando la cobertura promedio del follaje como variable independiente.
Factores ambientales y características del suelo no estuvieron significativamente correlacionados con producción de orégano.

INTRODUCCION

El orégano (Lippia berlandieri Schauer) es una especie importante encontrada en México la cuál crece silvestre, su uso como condimento y hierba curativa empezó en las antiguas culturas mexicanas y continua hasta el presente. En años recientes, la cosecha y procesamiento de hojas de orégano ha llegado a tener gran importancia económica. En México hay un gran número de personas que se benefician en éste recurso natural, ya que el 90% del total de la producción es destinada a la exportación.

Actualmente, la información sobre orégano es limitada. Un manejo adecuado de orégano requiere que los principales factores que influencian la producción de orégano en poblaciones naturales sean conocidos. Esta información es importante para optimizar la utilización del orégano, y al mismo tiempo establecer bases técnicas para los permisos anuales dados a los recolectores, ya que de ésta forma, una sobre-utilización de orégano puede ser prevenida.

[1]Trabajo presentado en la Reunión sobre - Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas. (University of Arizona, Tucson Az, 12-16 de Octubre de 1987)

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REVISION DE LITERATURA

Orégano

Orégano se refiere más propiamente a un sabor que a una planta en particular. Las plantas productoras de orégano incluyen miembros de los géneros Origanum, el cuál es cultivado y vendido como orégano, Lippia, Coleus, Thymus, Monarda Satureja, Hedeoma, Calamintha y Lantana (Foster 1984). Todas éstas plantas contienen altos porcentajes de fenol carvacrol y menores cantidades de timol en sus aceites esenciales y por lo tanto tienen un sabor y aroma a "Orégano", (Foster 1984, Heat 1972).

Las hojas de orégano son usadas para saborizar carnes, pescados, omelete, pozole, pizzas, espagueti, (Morton 1976). El orégano es tambien usado en la industria alimenticia de salsas y en encurtidos y como condimento de salsas picantes y en los chiles en vinagre (Nabham y Felger 1985).

En América Latina el orégano es estimado como hierba medicinal, al cuál se le han atribuído propiedades tales como estimulante, diaforético, emenagógico y carminativo. También ha sido usado para tratamientos de la indigestión, dolor de cabeza, tensión nerviosa y picadura de insectos. Los aceites esenciales de orégano también poseen propiedades fungicidas así como expulsivas de parasitos intestinales (Foster 1984, Cabrera 1980).

En México hay varias especies de plantas que tienen el nombre común de orégano, éstas especies pertenecen a las familias Verbenaceas, Labiadas y Compuestas; incluyendo en éstas familias a los géneros Lantana, Origanum, Gardo-

quia, Calamintha, Brickellia y otros más (Martínez 1979, Días 1976).
Lippia berlandieri es la especie más importante desde el punto de vista económico (Tabla 1).

Lippia berlandieri es un arbusto aromático de 2-3 m. de altura con hojas oblongas a elípticas de 1 a 6.5 cm. de largo y 5-30 mm de ancho. Tiene 4-6 pedúnculos por nudo, las espigas son oblongas de 4-12 mm, y la corola es amarillenta ó blanca. El orégano generalmente florea de Julio a Septiembre.

Tabla 1.--Especies conocidas como "Orégano" en México.

Familia	Especie
Verbenaceae	Lippia berlandieri Schauer.
"	Lippia palmeri Wats.
"	Lippia graveolens H.B.K.
"	Lantana involucrata L.
"	Lantana velutina Mart.et Cal.
Labiatae	Monarda austromontana Epl.
"	Monarda citriodora Cerv.
"	Origanum vulgare L.
"	Poliomintha longiflora Gray.
"	Calanintha potosina Schaff.
"	Gardoquia micromeroides Hemsl.
"	Hedeoma floribunda Standl.
"	Hedeoma patens Jones
"	Hyptis albida H.B.K.
Compositae	Brickellia veronicaefolia H.B.K.

(Correl y Jhonston 1970). Su distribución en México es en los estados de Chuihuahua, Durango, Jalisco, Zacatecas, Puebla, Querétaro, Tamaulipas, Oaxaca y Sinaloa (Martínez 1979).

El principal país importador de orégano mexicano es los Estados Unidos el cuál consume más del 85% de la exportación anual (Anuario Estadístico E.U.M. 1976-1985). De 1970 a 1985 los Estados Unidos importaron 26,072 toneladas de orégano con un valor total en aduanas de $ 41,496,000 dolares (Figura 1). Durante el periodo anterior México fué el mayor exportador a Estados Unidos con un volúmen total de 10.968 toneladas, y con un valor de $12,075,000 dolares (Departamento de Comercio de los Estados Unidos).

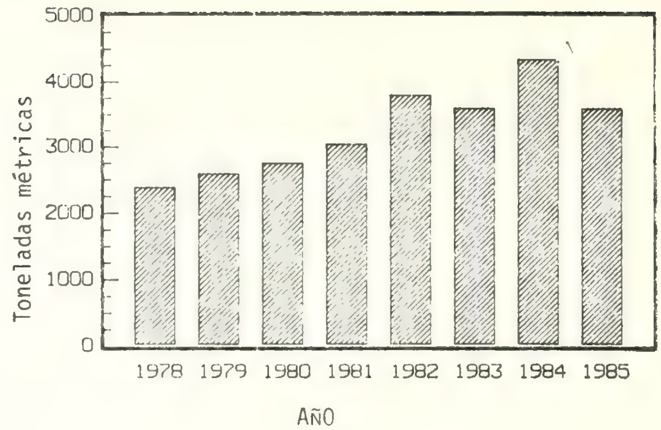

Figura 1.--Importaciones de Orégano en los Estados Unidos. Cantidad total en toneladas métricas de 1978 a 1985.

Estimación de Biomasa

Los métodos conocidos como análisis de dimensiones pueden ser usados para establecer relaciones entre biomosa y parámetros de la planta tales como el área de la cobertura aerea y volúmen del follaje. Los modelos desarrollados utilizando análisis de regresión pueden ser usados para estimar peso seco del follaje basado en dimensiones de la planta, las cuáles son más fáciles y más baratas de obtener (Ludwing et al 1975).

En estudios realizados en 8 especies de arbustos del desierto Chihuahuense para estimar relación en tamaño de la planta y biomasa, análisis de regresión fueron usados para obtener relaciones entre biomasa de la planta y área de cobertura y volúmen. Los mejores modelos para predecir biomosa fueron aquellos en los cuáles se uso el volúmen del follaje (Ludwig et al 1975).

En el caso de la gobernadora (Larrea divaricata) se ha encontrado que el mejor estimador para biomasa usando regresión linear simple fué el volumen de follaje como variable independiente (Burk and Dick-Peddie 1973).

Harrington (1979) estimó biomosa de hojas y tallos en árboles y arbustos de una comunidad de de Eucalyptus populnea, en éste estudio todos los arbustos mostraron alta correlación entre peso de hojas y tallos cuando se usaba altura y diámetro basal como variables independientes; él también concluyó que la altura da una mejor estimación de peso de brotes aereos en plantas con multiples tallos. En éste trabajo fueron hechas transformaciones logarítmicas de los datos para mejorar los coeficientes de correlación.

AREA DE ESTUDIO

El área de estudio está localizada en las cercanías de Colotlán, Jalisco a 230 Km. al Norte de la ciudad de Guadalajara. La elevación varía de 1700 a 2200 m. el área está caracterizada por lomeríos suaves. Las pendientes en los cerros varían del 5 al 40%.

El material parental está formado de extrusiones de rocas ígneas; los suelos están clasificados como luvisol háplico o litosol eútrico con lecho rocoso entre 25 y 50 cm. de profundidad (Cetenal 1973). Entre los sitios de orégano la profundidad de suelo era de 5 a 35 cm. con textura franco arenosa, el pH variaba de 5.8 a 6.5 y la materia orgánica de 3 a 4.5%.

El clima es semiseco con patrón de lluvias de verano, la precipitación media anual es de 660.5 mm con 83% de la lluvia cayendo de Junio a Septiembre en forma de fuertes tormentas, el mes más lluvioso es Julio con 166.1 mm (García 1981). La temperatura media anual es de 21.4°C con promedio mensual de Abril a Octubre sobre los 20°C (García 1981).

La vegetación del área de estudio pertenece al Matorral Subinerme. La especie dominante en los sitios donde los datos fueron colectados fué orégano (Lippia berlandieri). La flora asociada a orégano se puede dividir en 3 estratos. El herbáceo que incluye zacates tales como Bouteloua filiformis, Rinchelytrum roseum, Botriochloa saccharoides, Muhlenbergia monticola, Aristida adscenciones así como numerosas especies efímeras no identificadas. El estrato herbáceo en el cuál el orégano fué dominante tambien incluyó Mimosa biuncifera, Stevia rhombifolia, Brickellia veronicaefolia, Dodonea viscosa, Opuntia sp., Agave sp. y otras. Ipomea intrapilosa, Acacia farnesiana, Acacia schaffneri, Bursera fagaroides y Ptelea trifoliata fueron encontradas en el estrato arboreo.

METODOS

Un reconocimiento general de las áreas económicamente importantes para recolección de orégano fué llevado a cabo previo al muestreo. Los sitios fueron seleccionados en bases de homogeneidad de vegetación y otras características físicas que incluyeron pendiente, exposición y tipo de suelo.

El muestreo fué al azar dentro de cada sitio. La densidad de plantas de orégano fué el parámetro medido en cada parcela para calcular el tamaño de muestra en cada sitio. El tamaño de parcela fué de 30 m^2 (3 X 10m). Un total de 62 parcelas fueron muestreadas en 10 sitios. La altura de plantas de orégano fué medida desde la base del suelo hasta la parte más alta del follaje. Diámetro mayor de cobertura (follaje) y su diámetro menor el cuál era perpendicular al diámetro mayor fueron medidos. Diámetro promedio de cobertura (follaje) fué la media del diámetro mayor y del diámetro menor. El área de cobertura fué determinada usando la ecuación del círculo. Volúmen del follaje fué estimado usando la ecuación para volumen de un elipsoide 1/6 PIXalt X Diam. mayor X Diam. menor.

Para estimar peso de hoja seca se seleccionaron 317 plantas de orégano, éstas plantas fueron escogidas de entre todos los sitios y fueron representativas de todo el rango de plantas encontradas en la muestra. Las dimensiones del follaje (cobertura y volumen) fueron medidas como se describieron anteriormente. Todas las hojas de orégano, incluyendo ramas fueron removidas manualmente de éstas plantas. La técnica de cosecha fué diseñada para simular la técnica usada por los campesinos cuando recolectan orégano. El peso seco de hojas para todas las plantas fué medido en el laboratorio después que las muestras fueron secadas en estufa por 24 horas a 85°C. Después que el follaje de cada planta fué secado, las hojas y ramas fueron separadas manualmente y pesadas.

Los parámetros ambientales medidos fueron: elevación en metros, pendiente y exposición.

Muestras de suelo fueron tomadas en el centro de cada parcela y fué determinada la profundidad y características físicas (textura) y químicas del suelo (ph, conductividad eléctrica, % de materia orgánica, nitrógeno total, P,K,Ca,Mg y Na).

Los datos fueron transferidos a una computadora para análisis. Análisis de regresión linear fueron usados para desarrollar modelos para predecir la producción de hoja seca. El peso de hoja seca de orégano fué la variable dependiente; las variables independientes en los modelos incluyeron altura, diámetro mayor de follaje, diámetro menor, promedio de cobertura y volumen de follaje.

Las tablas de frecuencia para la altura y diámetro promedio de cobertura fueron también computadas para la población de orégano en cada sitio.

Análisis estadísticos consistentes en regresión linear simple y coeficientes de correlación fueron usados para evaluar el grado de asociación entre cada factor físico y químico del suelo y producción de hoja de orégano en cada sitio.

RESULTADOS Y DISCUSION

Flora asociada

Bouteloua filiformis fué la especie dominante en el estrato herbáceo, estando siempre presente dentro de las parcelas de muestreo, su cobertura variaba de 2.5 a 62.0%

La especie dominante en el estrato arbustivo fué el orégano (Lippia berlandieri) con una cobertura de 17.5 a 62.0% Otras especies de arbustos incluyeron Gymnospermum glutinosa, Brickellia veronicaefolia, Mimosa biuncifera y otras especies todas ellas con un total de cobertura menor a 2% cada una.

Especies en el estrato arboreo incluyeron

Ipomea intrapilosa, *Acacia farnesiana*, *A. Schaffneri* y *Ptelea trifoliata*, todas éstas especies tenian una cobertura menor al 3%.

Población de orégano en el Area de Estudio.

La densidad media de plantas en el área de estudio varió entre sitios. La densidad media varió de 18.7 a 75.6 plantas por parcela lo que dá una densidad media de 6,236 a 25,500 plantas por hectárea. El peso promedio de hoja seca -- por parcela varió de 307.3 gr. a 1166.6 gr. (Tabla 2). Test múltiple (Diferencias mínimas significativas) y análisis de varianza para densidad y producción de hoja seca de orégano mostraron diferencias significativas entre sitios al 95% de nivel de confianza.

Correlación de densidad media de plantas y producción media de hoja seca por parcela fué R=0.803. Como es indicado por la significancia del coeficiente de correlación, la producción - media por parcela generalmente se incrementa cuando la densidad por parcela se incrementa.

Tabla 2.--Densidad media de plantas de orégano y producción promedio de hoja seca de orégano en gramos por parcela en cada uno de los sitios parcela = 30 m^2.

Sitio	Densidad	Producción
3	18.71	307.26
6	22.28	435.66
9	23.00	453.41
1	23.57	615.64
10	38.00	705.53
8	47.33	922.23
7	49.57	1166.64
2	61.50	954.33
5	65.20	1076.28
4	75.60	827.61

La mayoría de las plantas de orégano caen en 3 categorías de altura que fueron 31-45 cm. 46-60 cm y 61-75 cm; éstas categorías incluyeron el 54% de la población total de orégano. Las plantas de orégano usualmente crecen arriba de un metro en ausencia de cosecha; sin embargo fueron cosechadas anteriormente en forma manual removiendo la porción superior, a ésto se debe el pequeño porcentaje de plantas alcanzando alturas de 135-200 cm. (2%). El 55% de todas las plantas de orégano tenían diámetro promedio de cobertura entre 21 y 50 cm.

Predicción de peso de hoja seca.

Los modelos para predecir peso de hoja seca por planta estuvieron basados en datos de 317 plantas. Los modelos iniciales tenian peso de - hoja seca como variable dependiente y diámetro promedio de cobertura, altura, área de cobertura y volúmen de follaje como variables independientes.

Para lo anterior fué utilizado un modelo linear aditivo (Y = bo+BiX-ei).

El modelo que tuvo mejor ajuste para peso de hoja seca fué cuando se usó área de cobertura cocomo variable independiente. El coeficiente de determinación fué igual a 0.82 y el error estandar fué 12.15 gramos por planta. El modelo basado en altura resultó en una pequeña R^2 (0.56) y gran error estandard (22.5) gr. por plantas, ésta diferencia en ajuste pudiera ser atribuída a la manera en la cuál las plantas son cosechadas. La producción está basada en crecimiento anual y el área de cobertura puede ser la misma para plantas con un rango de altura de 45 a 105 cm. Esto ocurre debido a que la porción superior de las plantas es removida en la cosecha anual, causando un incremento en crecimiento lateral (Tabla 3)

Usando transformaciones de log base y para ambas variables, dependiente e independiente, se incrementó significativamente el coeficiente de determinación. Las variables independientes diámetro promedio de cobertura, área de cobertura y volúmen de follaje, todas resultaron en ecuaciones teniendo similar R^2 (0.95) y similar error estandard (0.35). Análisis de varianza para cada uno de éstos 3 parámetros fueron significantes al 95% de nivel de confianza. Por lo tanto cualquiera de éstos parámetros pudiera ser usado para predecir peso de hoja por planta, sin embargo, en el campo es más práctico el uso de diámetro promedio de cobertura porque se involucra un menor número de cálculos (Tabla 4, Figura 2).

Tabla 3.-- Modelos de regresión linear simple usados para predecir peso de hoja seca de orégano (PHS), usando diámetro promedio cobertura (DPC), altura (ALT) área de cobertura (AREA) ó volumen de follaje (VOL) como variables independientes. (P 0.05).

Modelo	R^2	Error estandard
PHS = -19.778+1.0342(DPC)	0.84	13.5084
PHS = -9.214+0.6069 (ALT)	0.56	22.5084
PHS = 1.898+0.0115 (AREA)	0.87	12.544
PHS = 9.927+1.283 E-4(VOL)	0.82	14.5688

Tabla 4.-- Modelos de regresión linear simple usando transformaciones log base e para predecir peso de hoja seca de orégano (PHS) (P 0.05)

Modelo	R^2	Error estandard
Ln PHS = -4.802+2.023 (In DPC)	0.95	0.352
Ln PHS = -4.496+1.006 (In AREA)	0.95	0.349
Ln PHS = -4.935+0.706 (In VOL)	0.95	0.340

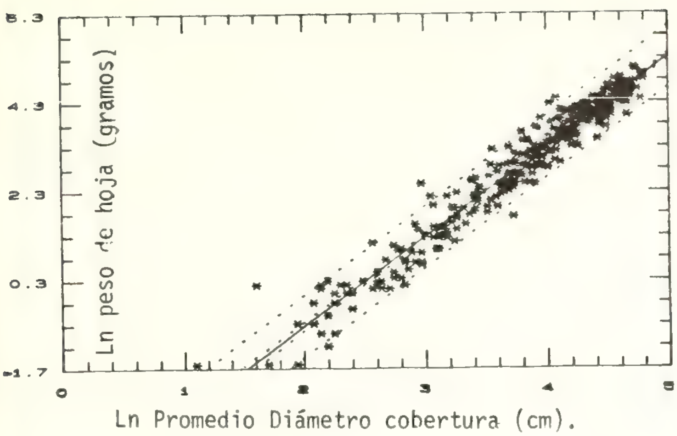

Figura 2. Regresión de log peso de hoja seca sobre log diámetro promedio de cobertura.

En adición a los modelos de regresión linear simple se corrieron modelos de regresión múltiple, usando peso de hoja seca, como variable dependiente y diámetro promedio de cobertura, altura, diámetro mayor y menor como variables independientes. El uso de modelos de regresión múltiple no resultaron en una mejoria significante comparándolos con aquellos obtenidos usando regresión linear simple (Tabla 5).

Tabla 5.-- Modelos de regresión linear múltiple para predecir peso de hoja seca de orégano (PHS).

Modelo	R^2
PHS = -19.553+0.416 (DMAY)+0.58 (DMEN)	0.84
PHS = -20.699+0.414 (DMAY)+0.55(DMEN)+0.71 (ALT)	0.84
PHS = -20.969+0.959 (DPC)+0.070 (ALT)	0.84

La porción recolectada en cada planta de orégano incluyó hojas y ramas, por lo tanto la relación que existía entre ramas secas más hojas y peso de hojas secas fué estimada. El modelo linear simple que mejor explicó esta relación fué:

Peso hoja seca = 1.103+0.391 (Peso seco de hoja + ramas).

$R^2 = 0.97$

Error estandard = 0.004

El análisis de varianza para éste modelo fué significativamente al 95% de nivel de confianza. Este modelo puede ser usado para predecir peso de hoja seca basado en el peso total de tallos más hojas. El uso de éste modelo podría eliminar mucho de la necesidad para la separación manual de hojas de las ramas y tallos. El promedio de peso de hojas secas de cada planta osciló entre 35-45% del peso total cosechado que incluyó tallos, ramas y hojas.

El uso de medidas de cobertura en orégano para predecir biomosa aérea mostró resultados similares a otros investigadores que trabajaron con algunas especies arbustivas del desierto Chihuahuense (Ludwing et al 1975). Adicionalmente éstos modelos fueron similares a aquellos obtenidos por Burk y Dick-Peddie (1973) para predicción de biomosa aérea en gobernadora (Larrea divaricata). Esta similaridad da una mayor confianza en la bondad de éstos modelos de orégano y su utilidad potencial para predecir biomasa aérea de orégano en sitios fuera del área de estudio.

El uso de transformaciones para mejorar los coeficientes de correlación mostraron resultados similares a Harrington (1979) que usó transformaciones para predecir biomasa aérea en arbustos y árboles en una comunidad de Eucalyptus.

Los modelos que mejor predicen peso seco de hoja de orégano y particularmente aquellos faciles de aplicar tales como regresión linear simple sobre área de cobertura ó diámetro promedio de cobertura usando transformaciones (log base e) pueden ser usados en manejo de orégano en áreas en las cuáles ésta especie es economicamente importante. Estos modelos podrían ser usados por personal responsable del otorgamiento de permisos para explotación de orégano, los cuáles podrían muestrear sitios y hacer mejores estimaciones de producción de hoja seca en el área; basados en éstas estimaciones el número de permisos anuales podrían ajustarse en relación al potencial del sitio.

RELACION DE SUELO Y FACTORES AMBIENTALES Y PRODUCCION DE OREGANO

Los análisis estadísticos mostraron que características tales como textura y profundidad del suelo tenian baja correlación con producción de orégano. Los nutrientes analizados fueron N, P, K, Ca, Mg, Na, los análisis de varianza para éstos nutrientes en relación a producción de orégano, mostraron diferencias no significativas al 0.05 de nivel de confianza.

Respecto a la exposición se vió que no estaba relacionada a producción de orégano. Las pendientes variaban del 5 al 25% en todos los sitios y no fué encontrada relación entre pendiente y producción de orégano. Todos los sitios tenian 50-60% del área cubierta por lecho rocoso. La altitud varió de 1700 a 2000 m y no estaba correlacionada con producción.

CONCLUSIONES

La cosecha y procesamiento de hojas de orégano tiene importancia económica en México, debido a que un gran número de individuos se benefician de este recurso, ya que casi la producción entera es exportada.

Los modelos de regresión fueron usados para predecir producción de hoja de orégano basados en dimensiones de la planta y éstos pueden ser utilizados para hacer estimaciones de producción potencial en sitios de orégano; tales predicciones harían posible un mejor control de la explotación y así evitar una sobreexplotación.

La cosecha de orégano en México se ha estado incrementando en los últimos 10 años y probablemente se incrementará más en el futuro, por lo tanto es necesario conocer como las poblaciones naturales de orégano responderán a una intensiva y continúa cosecha.

La investigación futura debería enfocarse como el vigor del orégano es afectado por una continuada cosecha y cuales son los efectos de la cosecha manual tradicional en la regeneración en poblaciones naturales.

El manejo e investigación del orégano debería enfatizar sobre la recolección apropiada que preserve y mejore éste valioso recurso natural.

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MANEJO DE PINOS PINONEROS PARA LOS PINONES[1]

Elbert L. Little, Jr.[2]

Resumen.--Se ofrecen algunas sugerencias sobre el manejo de pinos piñoneros para las semillas comestibles o piñones bajo uso múltiple. Especies mexicanas como Pinus maximartinezii merecen investigaciones en parcelas. Es deseable utilizar genética forestal. Se puede aumentar la cosecha de semillas. Se necesita más maquinaria para descascar las semillas.

INTRODUCCIÓN

Basado en sus investigaciones hace medio siglo y observaciones después, el autor desea ofrecer algunas sugerencias sobre el manejo de pinos piñoneros para las semillas comestibles o piñones. Durante cuatro años desde 1937 hasta 1941 hizo estudios en Arizona y Nuevo México, mayormente con Pinus edulis Engelm., la especie más extensa en Los Estados Unidos (Little 1965, 1977). En esa época el producto más valioso era la semilla comestible, como explicó una nota, Managing Woodlands for Piñon Nuts (Manejando Bosques para Piñones) (Little 1941). El trabajo fue interrupido por la Segunda Guerra Mundial y no fue resumido hasta algunos años después. Sin embargo, mucho ha cambiado durante medio siglo.

Los pinos piñoneros de Pinus subsect. Cembroides han sido el sujeto de numerosas investigaciones. Las publicaciones incluyen las memorias de conferencias y simposios (Gifford y Busby 1975; Aldon y Loring 1977; Everett 1987), un libro (Lanner 1981) y bibliografías (Aldon and Springfield 1973; West, Cain, and Gifford 1973). Los resumenes más recientes para las dos especies importantes en los EE. UU. son: Pinus edulis (Ronco 1987), P. monophylla Torr. & Frem. (Meeuwig & Budy 1987). Se debe mencionar el II Simposio Nacional sobre Pinos Piñoneros [México, D.F., México, 6-8 agosto 1987] (Memorias en prensa). Muchas otras investigaciones sobre el manejo de los bosques de pinos piñoneros con especies de junípero o sabino (Juniperus) están en progreso.

Una conclusión es: Los investigadores y los administradores o dueños deben trabajar juntos en el manejo de los bosques bajo uso múltiple. Otra conclusión es: El manejo está limitado por la producción baja debido a la escasez de agua y la interacción de costo/beneficio.

ESPECIES IMPORTANTES DE PINOS PIÑONEROS

Las dos especies importantes de pinos piñoneros en los EE. UU. son Pinus edulis y P. monophylla, mencionadas antes. En México los piñones de comercio pertenecen mayormente a dos especies: P. cembroides Zucc. y P. nelsonii Shaw.

Otras especies mexicanas merecen investigaciones también para sus semillas comestibles de valor comercial posible. Deben probar todas especies en parcelas o plantaciones pequeñas experimentales.

Pinus maximartinezii Rzed. es local y escasa en el sur de Zacatecas (Rzedowski 1964). Es muy distinta desde las otras especies de Pinus subsect. Cembroides. Esta especie tiene conos muy grandes con muchas semillas muy grandes. Las semillas con cáscara dura miden de 2-2.5 cm. de largo y tienen 3 o 4 veces el peso de las otras especies. Debido a las semillas grandes, esta especie tiene prioridad alta.

Pinus remota (Little) D. K. Bailey & Hawks. se encuentra en Coahuila y Chihuahua en el noreste de México y local en el suroeste de Texas. Se ha llamado "paper-shell pinyon" (piñón con cáscara como papel) en referencia a su cáscara fina o delgada.

Pinus monophylla Torr. & Frém. (en el sentido ancho, incluyendo P. californiarum D. K. Bailey como variación) se distribuye desde la Gran Cuenca de los EE. UU. hasta el norte de Baja California (Bailey 1987). Tiene semillas grandes con cáscara delgada. La variación en México es de interés especial debido a las semillas aceitosas en vez de harinosas.

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[1]Ponencia presentada en la Reunión Estrategías de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Áridas. [Tucson, Arizona, 12-16 octubre 1987].

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ESTRATEGÍAS DE CLASIFICACIÓN Y MANEJO

Las estrategías de clasificación y manejo de bosques de pinos piñoneros bajo uso múltiple son semijantes a esos en otros tipos de vegetación silvestre. Primero, se desea un inventario forestal y clasificación de sitios, incluyendo topografía, erosión, usos presentes, daños por sobrepastoreo, etc. Debe corregirse cualquier daños, por ejemplo, por erosión acelerada y por sobrepastoreo. Algunos terrenos marginales, como muy rocosos y pendientes o dañados por sobrepastoreo, quizás deben clasificarse sin uso por ganado. Terrazas y surcos por las curvas de nivel pudieran conservar ambos los suelos y el agua. Las especies difieren no solamente en su distribución pero en el manejo. Una conclusión es: Los investigadores y los administradores deben trabajar juntos en el manejo de los bosques bajo uso múltiple.

Los planes para manejo deben proveer alimentos y otros productos útiles y también empleo para la gente que vive cerca del bosque. Los usos pueden incluir semillas comestibles, leña, postes, madera para minas, tablas, árboles de Navidad, forraje, agua, control de erosión, vida silvestre, recreo, paisaje, etc. También, se puede clasificar cada área o parcela por su uso o valor mas importante. Por ejemplo, una área pública adyacente a un rancho quizás es importante para el forraje. Otra área montañosa y rocosa con faldas muy inclinadas y encima de una represa quizás debe estar cerrada a ganado. Cerca de un pueblo, leña sea importante. Etc.

Trabajo Manual.--Con utilización intensa y comercialización, el manejo de pinos piñoneros incluyendo las cosechas requiere mucho trabajo manual. Es limitado en los EE. UU. Afortunadamente, en México muchos braceros y campesinos están a mano.

Conversion.--Hace unos veinticinco años alrededor de un millón de hectáreas de bosques de pinos piñoneros y juníperos (*Juniperus* spp.) en los Bosques Nacionales y otros terrenos públicos en los EE. UU. fueron destruidos y convertidos a pastura (Arnold et al 1964). Se usaban las palabras "invasión" en las pasturas o praderas y "control." Mejor dicho, fue "eradicación" o "conversión." También, sembraron semillas de Gramíneas para mejorar el forraje. Después, los juniperos empezaban a regresar. Parece que la conversión sea transitoria y no permanente. Estudios del costo/beneficio serían deseables antes de hacer más conversión.

REGENERACIÓN ARTIFICIAL

Bajo uso múltiple la producción de los bosques de pinos piñoneros y juníperos pudiera mejorarse. En el futuro estes bosques crecerán más productos y proveerán más trabajo para la población aumentanda. El manejo esta limitado por la producción baja debido a la escasez de agua y la interacción de costo/beneficio.

Regeneración artificial debe ser considerado en el futuro, por ejemplo, en los sitios mejores, areas desnudas por corte e incendios.

Parcelas Experimentales.--Es importante empezar pronto algunas parcelas experimentales debido al crecimiento despacio de los árboles, hasta medio siglo o mas hasta la madurez. (El autor lamenta que no estableció unas parcelas hace medio siglo!) Primero, las especies superiores deben probarse con semillas de árboles superiores. Parcelas pequeñas de cien plantulas para cada especie serían muy útiles.

GENÉTICA FORESTAL

Es importante utilizar los metodos de genética forestal en investigaciones con regeneración artificial y plantaciones.

Selección.--Siempre cuando se recoge semillas de pinos piñoneros para sembrarse, debe buscar los árboles superiores (plus). Por ejemplo, la selección de árboles con muchos conos y muchas semillas grandes, crecimiento rápido y forma extendida. Es deseable marcar cada árbol con un rótulo. Se puede establecer huertas de los árboles superiores como un fuente de semillas. La propagación vegetativa por injertos y plantitas es una posibilidad.

Hibridización.--La mejoría de pinos piñoneros por hibridización es una posibilidad. Sin embargo, pudiera ser despacio y difícil. Pocos híbridos entre las especies en los EE. UU. han sido producido por Institute of Forest Genetics, U.S. Department of Agriculture Forest Service, Placerville, California.

COMERCIALIZACIÓN

Se dice que los piñones (*Pinus edulis* y *P. monophylla*) son las árboles silvestres (también no en cultivo) más importantes para las nueces comestibles en todos los EE. UU.

Hace medio siglo el producto más valioso de *Pinus edulis* era la semilla comestible, el piñón (pinyon nut o Indian nut en inglés). La cosecha anual variaba entre 500,000 y 1,000,000 kilogramos cada año (máxima más de 3,000,000 kg en 1936). Ahora la cosecha anual es solamente pocas miles de kilogramos, mayormente para consunción local y recreo. La cosecha anual de *P. monophylla* ha sido baja durante los años, pocas miles de kilogramos anualmente. Por seguro la cosecha puede aumentarse.

Producción de Semillas.--La producción anual de conos y semillas en *Pinus edulis* es muy irregular, como en algunas otras especies de árboles. En la mayoría de años la producción de conos en una localidad es baja y consumida por insectos y la vida silvestre, no suficiente para cosecha comercial por humanos ("bumper crop" en inglés).

No hay producción comercial todos los años en la misma localidad. Sin embargo, en cada año hay producción comercial en alguna parte de la distribución extensa de la especie. Se dice que el intervalo entre producciones comerciales en una localidad es "cada siete años" pero varia mucho. Puede ser de 3 a 5 o 7 años, raramente 2. Parece que la producción comercial es más frecuente en la parte norte de la distribución que hacia el sur. En algunas localidades hacia los límites de distribución, no hay producción commercial, por ejemplo, Arizona central, cerca del límite al suroeste.

Parece que la irregularidad en la producción de conos posiblemente sea asociada con variaciones en precipitación o la temperatura. Forcella (1978, 1981a, 1981b) concluyo que los primordios de conos tuvieron una correlación con temperaturas bajas durante el verano tarde o la última semana de agosto y la primera semana de septiembre y que se pudo estimar la producción de conos en adelante. Más estudios son deseables.

La Cosecha.--La primera etapa en la comercial ización de piñones es el aumento en la cantidad de semillas recogidas. Naturalmente la cosecha debe ser suficiente para las ventas continuas por todo el año desde una cosecha hasta la próxima.

Métodos de Cosecha.--Parece que se puede aumentar la cosecha de piñones por métodos mejores. Con *Pinus edulis* se cogen las semillas desde el suelo una por una con los dedos por el otoño después de abrir los conos temprano en las dos primeras semanas de octubre. La cosecha puede continuar hasta el invierno o hasta la vida silvestre y los humanos han recogido todo. Este método es despacio y produce menos de un kilogramo por hora por persona. Otro metodo es de robar los nidos de ratones. También, se puede usar una escoba bajo los árboles y después un cedazo parar separar la hojarasca. Posiblemente se pudiera inventar un tipo de limpiador aspirante para sacar las semillas desde el suelo.

Con *Pinus monophylla* se colectan los conos en el árbol antes de arbrirse. Después los conos secan y se abren y descargan las semillas. Los cosecheros suben los árboles o usan palos o ganchos de podar. Este método se emplea también con otras especies en México. Como los conos se abren temprano en *P. edulis*, el tiempo para coger los conos cerrados sería muy corto, solamente pocas semanas. (Los conos rinden mucha resina pegajosa. Un método fácil de limpiar las manos es lavarlas con borax (polvo) y agua.)

El método más fácil de aumentar la cantidad de piñones en el mercado es sencillo, solamente cojer más semillas en cada otono. Todos los años la producción es más grande que la cosecha y la venta. Durante algunos años el Servicio Forestal de los EE. UU. con la ayuda de los guardabosques distribuía pocos meses en adelante una lista de las áreas en los Bosques Nacionales donde los conos inmaduros eran abundantes.

Otro método de aumentar la cosecha es de ofrecer precios más altos a los cosecheros. Entonces el precio en el mercado al detalle subiría. Generalmente los cosecheros no pagan nada en los terrenos públicos de los EE. UU. Sin embargo, el Bureau of Land Management cobra poco por libra.

EL MERCADO

Un programa de anuncios y promoción sería útil y provecheso en la expansión del mercado, particularmente para los turistas. Por ejemplo, los piñones como una nuez silvestre eran un alimento principal de los indios, que eran almacenado por todo el año. También, a causa del precio alto, el piñón es una nuez de lujo en parte con sabor distinto y debe ser ofrecido en tiendas especiales de nueces. Naturalmente esta nuez silvestre no puede competir en precio con las nueces commerciales cultivadas en cantidades, por ejemplo, el maní o cacahuete.

Semillas sin Cáscara.--Parece que se puede aumentar el mercado de semillas o almendras tostadas sin cáscara o testa. Las semillas de algunas especies de pinos piñoneros tienen la cáscara dura, demasiada gruesa para romper con los dientes, por ejemplo, *Pinus cembroides*. El peso de la cáscara varia entre las especies, aproximadamente una tercera del total en *Pinus edulis* y la mitad en *P. cembroides*. También, dentro de pocos meses después de la maduración, la nuez fresca pierde casi un tercero de su peso en secarse.

Las semillas crudas de *Pinus edulis* pueden ser almacenado más de un año en el clima seca de Nuevo México. Se dice que las semillas de *P. monophylla* llegan a ser rancias en almacenaje.

Se venden los piñones tostados en paquetes transparentes, ambos con cáscara y sin cáscara. También se preparan dulces con piñones. Este mercado merece aumentarse con una promoción. Las semillas sin cáscara y tostadas pueden entrar el mercado internacional. Por ejemplo, en los Estados Unidos se importan semillas sin cáscara de pignolia (piñón o pine nut) de *Pinus pinea* L. desde la región Mediterránea de Europa, mayormente Italia y España, y semillas (pine nut) de *P. armandii* Franch. desde China.

Análises Químicas.--Nuevas análises químicas se desean para promover la venta de los piñones. Las especies difieren en la composición química y el sabor. Por ejemplo, *Pinus edulis* tiene la semilla aceitosa y *P. monophylla* la semilla harinosa. Otras especies y variedades nombradas y reconocidas en años recientes faltan las análises químicas. *P. cembroides* Zucc. difiere de las otras en la almendra o endosperma o parte comestible de color rosado en vez de blanco.

Maquinaria.--Es esencial desarrollar más maquinaria para separar la cáscara o testa dura desde las semillas para las varias especies de pinos piñoneros. El método de remover o sacar la cáscara a mano es despacio y caro y no muy limpio. Hace más de medio siglo una companía en Nuevo México inventó una máquina para su propio uso con semillas de Pinus edulis.

Quizás se puede conseguir la maquinaria desarrollada para otras especies de piñones. O la maquinaria para nueces, frijoles, manís o cacahuetes, avellanas, etc., pudiera adaptarse. En un trabajo sobre las semillas comestibles de pinos en el mundo, Harrison (1951) mencionó el proceso de descascarse por máquina.

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INDICE DE DIVERSIDAD DE ESPECIES PARA DETERMINAR TAMANO DE MUESTRA EN VEGETACION DE BAJA CALIFORNIA SUR[1]

Ricardo Almeida Martínez[2], Homero Fraga Mancillas[3], y Jorge Agúndez[4]

En seis exclusiones en el sur de Baja California, se hicieron inventarios de vegetación empleando cuadrículas de 25 m^2 considerara como unidad de muestra,esto permitió realizar evaluaciones de indice de diversidad de especies con el fin de encontrar un nivel deseable de información. En todos los casos se muestra una tendencia progresiva, solo en dos localidades se lograron niveles satisfactorios de información.

INTRODUCCION

El Estado de Baja California Sur,se localiza en el Noroeste de la República Mexicana, en la Península del mismo nombre ocupando la mitad sur de la franja continental. Colinda al norte con el Estado de Baja California, al sur y oeste con el Océano Pacífico y al Este con el Golfo de California. Su territorio está formado por 7'367,700 hectáreas, considerándose estadísticamente una superficie forestal de 5'653,000 hectáreas de las cuales 5'488,400 corresponden a comunidades bióticas de zonas áridas y semiáridas y 164,800 a bosques de clima templado. En esta superficie se estima una riqueza florística formada por mas de dos mil especies arbóreas, arbustivas y herbáceas.

La vegetación de Baja California Sur, es conocida en cuanto a sus componentes florísticos a nivel de Desierto Sonorense (Shreve y Wiggins 1964); sin embargo, a nivel estatal existe poca información con respecto a la cuantificación de esos elementos. Una primera aproximación es considerar el número de muestras suficientes para interpretar cambios en la vegetación e impacto del pastoreo.

Diversos autores consideran a los indices de diversidad como una posibilidad para análisis del muestreo en la vegetación. La composición botánica establece unidades de muestra que son los taxa, que en este caso son las especies y en un segundo nivel de información se encuentra el area presentada por unidades de muestra. El objetivo de este trabajo fue conjugar la información que proviene de esas dos fuentes primarias de información en la exploración del recurso natural. Es por ello que se seleccionó al indice de diversidad de especies como una herramienta que combina los taxa y areas de muestreo, para determinar el area mínima de muestro.

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METODOLOGIA

El trabajo se inició en el extremo sur, en los municipios de Los Cabos y La Paz, con cercanía a la sede de la Universidad Autónoma de B.C. Sur, incluyéndose desde la vegetación influenciada por el litoral hasta la de la parte media alta, 850 a 1200 msnm.

En la zona agroecológica de Los Cabos,mediante prospección de campo, se seleccionaron seis sitios diferentes entre sí, con respecto al perfil vegetal y las condiciones edafofisiográficas, construyéndose exclusiones cuya superficie osciló entre 800 a 1200 m^2. Dentro de las exclusiones se trazaron cuadrículas de 25 m^2. En la figura 1 se observa el tipo de vegetación característica del Chaparral de B.C. Sur y en la figura 2 el pastoreo de cabras.

En esos seis sitios se establecieron exclusiones que protegen a la vegetación principalmente del impacto del pastoreo que es comun en el area, los lugares fueron: (1) La Capilla, (2) Boca del Salado (3) Palo Escopeta, (4) Santa Anita, (5) Migriño y (6) Pescadero. Dentro de las esclusiones se trazaron cuadrículas de 5 x 5 m^2 poniendo estacas en esquinas para estudios permanentes, cada cuadrícula representa una unidad de muestra. Aunque las superficies variaron de 500 a 1000 m^2, el número del cuadriculado fue en relación al area disponible. Se hizo un

Figura 1.--Exclusión de vegetación en el municipio de Los Cabos de Baja California Sur.

inventario y registro de la composición botánica de todas las exclusiones. En una primera fase se determinó la presencia de especies en cada exclusión para determinar similaridades, se consideró solo la vegetación perenne, excluyendo a la vegetación efímera que es la mas abundante.

Figura 2.--Pastoreo de la vegetación estudiada en Baja California Sur.

A posteriori se utilizó la información botánica y los datos de censos de la cuadrícula para determinar la información obtenida por cada unidad de muestra. Al acumular la información, al aumentar la superficie de areas contiguas, se representa diferente tamaño de muestra, así se obtuvo una serie de incremento de 25,50,75,...n, m^2. En un enlistado de especies, paralelamente al incremento de superficies se acumulaba el número de individuos y número de especies aparecidas.

Se determinó el índice de diversidad de especies para cada unidad de muestra, partiendo de un tamaño de 25 m^2 y los incrementos consecutivos empleando los indices de Brillouin y Shannon, utilizando forma de cálculo propuestas por Lloyd, et al, (1968) según fórmulas:

$$\text{Brillouin} \quad H' = \frac{1}{N} \log \left(\frac{N!}{n_1! \; n_2! \; . \; .n_s!} \right)$$

donde: N = número total de individuos

n = número dentro de cada especie

$$\text{Shannon} \quad H' = - \Sigma \; P_i \log P_i$$

donde: P_i = la proporción de la población muestreada.

La representación gráfica se utilizó para encontrar tendencias del indice de diversidad de especies contra el número de muestras.

RESULTADOS Y DISCUSION

La presencia de las diferentes especies encontradas en las seis exclusiones se muestran en el cuadro 1; se registran 44 especies, seis no identificadas taxonómicamente, aunque estas sí fueron consideradas en la determinación del indice de diversidad. Se puede observar un mínimo representativo de 12 especies para Palo Escopeta y un máximo de 24 para Boca del Salado. Las especies comunes a todas las exclusiones son: *Jathropa cinerea*, *Lemaireus thruberi*, *Machacrocereus gummosus* y *Opuntia cholla*, otras de importancia que aparecen como mínimo en cuatro esclusiones son: *Atiganon leptopus*, *Brusera microphylla*, *Cnydascolus angustidens*, *Colubrina glabra*, *Cytocarpa edulis*, *Ferrocactus sp.*, *Fouqueiria diguetii sp.*, y *Pachycereus pringlei*.

Estas observaciones preliminares solo incluyen la vegetación perenne, árboles y arbustos, las efímeras pueden representar un componente mayor.

Los resultados obtenidos por el indice de Shannon y Brillouin fueron similares para todos los casos, las magnitudes y tendencias presentan similaridad. En la figura 3 se muestra la correspondencia de los dos indices al considerar la exclusión de Santa Anita, aunque impacta el hecho de ver una *Plateau* que se inicia después de la quinta muestra que representa una superficie de 125 m^2 y termina a la novena, o sea una superficie muestreada de 225 m^2, para después mostrar un ascenso. En la comparación de diferentes indices y consideraciones de conceptos de diversidad hechos por McIntosh (1967) no se muestras los límites mínimos y máximos obtenidos por simulación, aunque si presentan un ajuste operacional para establecer esos límites en una escala de 0 a 1.

En Santa Anita solo se repitieron 12 cuadrículas acumuladas cubriendo 250 m^2, según la gráfica se detecta aumento progresivo, se puede

interpretar que se requiere una mayor superficie a muestrear para conservar un nivel de manera estabilizada, o descenso.

CUADRO 1.-- Presencia de especies vegetales en las diferentes exclusiones en los Municipios de La Paz, Los Cabos, B.C.S. (México) 1985.

ESPECIES VEGETALES	1	2	3	4	5	6
Adelia virgata				.		.
Antiganon leptopus	.	.		.	.	.
Bursera microphylla	.	.	.	.	.	
Caesalpinia sp.	.	.				
Cassia goldmani	.			.		
Cercidium floridium			.			
Cnydascolus angustidens	.	.		.	.	
Colubrina gla ra	.	.	.		.	
Cyrtocarpa edulis	.	.	.	.	.	
Erithrina flavellifarmis	.					
Esembeckia flava						.
Ferrocatus sp.	.		.	.	.	.
Fouquieiria diguetii	.	.	.	.	.	
Gossypium davidsoni				.		
Haematoxilon brasiletto			.			
Helianthus sp.				.		
Indigofera fruticos	.	.		.		
Jatropha cinerea	.	.	.	.	.	.
Jatropha cuneata		.				
Karwinskia humboldtriana	.				.	.
Lemaireus thurberi	.	.	.	.	.	.
Lippia palmero						.
Lycium sp	.	.	.			
Lysiloma divarciata	.		.			
Machaerocereus gummosus	.	.	.	.	.	.
Mamillarias sp.	.	.	.		.	.
Melochia tomentosa				.		
Mimosa xanti	.			.		
Opuntia cholla	.	.	.	.	.	.
Opunta sp.						.
Pachycereus pringlei		.	.	.	.	.
Pedilanthus macrocarpus		.		.		
Phithecellobium confine	.		.			
Ruellia sp		.				
Simmondsia chinensis		.				
Solanum sp	.			.	.	
Turnera diffusa	.	.		.	.	
Yuca válida	.				.	
No identificadas (6)						

1. BOCA SALADO
2. PESCADERO
3. CAPILLA
4. MIGRIÑO
5. SANTA ANITA
6. PALO ESCOPETA

En estudio de etapas sucesionales se ha encontrado que hay una tendencia de descenso en las últimas etapas de sucesión (Harger y Tustin, (1973).

En la figura 4 se presentan los resultados de dos localidades, Migriño y Boca de Salado. El propósito es ver la tendencia a medida que aumenta la superficie muestreada y los niveles del indice de Brillouin. El nivel máximo para Migriño es de10 al considerar una superficie de 21 cuadrículas, o sea 525 m^2.

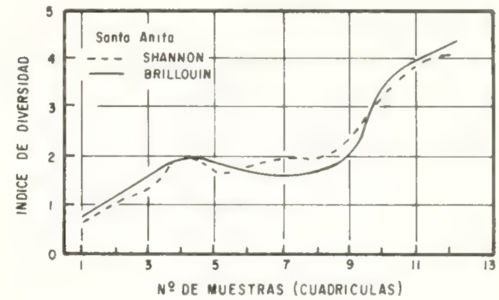

Figura 3.--Comparación de los indices de diversidad de especies de la exclusión de Santa Anita, B.C.S. (México).

En Boca del Salado la superficie de 35 cuadrículas sumó 850 m^2 y la tendencia de ascenso fue consistente.

Tanto Wittaker (1972) como Harger y Tustin (1973), consideran que los indices no apoyan a una comparación entre comunidades, en este caso solo nos indican que para el caso de Boca de Salado es conveniente aumentar el area de muestreo.

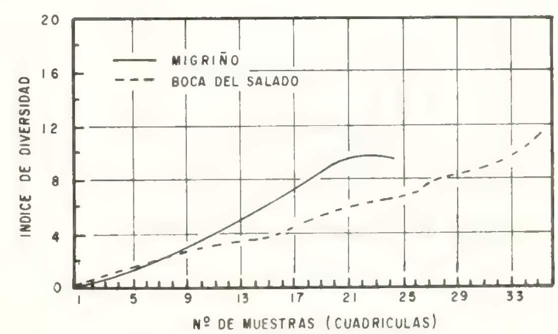

Figura 4.--Tendencia del indice de diversidad de especies en Migriño y Boca de Salado, B.C.S. (México)

Los resultados para Palo Escopeta, La Capilla y Pescadero se muestran en la figura 5. La composición florística de Palo Escopeta fue mas rica en comparación a todas las comunidades, es posible que su ajuste al indice de diversidad de especies sea diferente, las simulaciones de poblaciones realizadas por Meltshe y Forrester encontraron en 10 especies y 250 simulaciones que según el indice de Brillouin hay una distribución con pico bajo y otra con pico alto de acuerdo a las densidades determinadas por los individuos de esas 10 especies.

El pico para Palo Escopeta se encuentra en 10 cuadrículas (250 m^2) y un indice de 4.3 mientras que los de La Capilla y Pescadero,

siguen con la tendencia de ascenso.

En estos dos casos se puede interpretar que se requiere una mayor superficie para lograr un nivel de equilibrio o pico con su descenso.

Los indices de diversidad de especies se han utilizado para el estudio de comunidades en diversas maneras, amplia literatura reporta Dennis (1979), pero es hasta fechas recientes que se procura su utilización para determinar tamaño de muestra (Heltshe y Forrester, 1985), pues se considera en principio que para obtener repetición de muestra se requiere de un tamaño fijo y con poblaciones homogéneas en tiempo y espacio, condiciones que no se presentan en manera natural. Sin embargo, en este estudio se emplea como una aproximación para definir area que proporcione suficiente información para cada localidad de manera independiente, y lograr un indice que satisfaga una información de su componente florístico para fines de su cambio sucesional o provocada por manejo del recurso en areas contiguas a las exclusiones. Los datos y superficies que se han estudiado muestran la necesidad de un mayor contenido de información,por ende mayor superficie como tamaño de muestra para cuatro de los seis casos estudiados, por encontrarse tendencias de ascenso contínuo.

CONCLUSION

Los indices de diversidad de especies nos indican que se requiere de una mayor superficie para obtener un tamaño de muestra satisfactorio, que posiblemente se deba a que la vegetación natural de Baja California Sur se presenta bastante dispersa y la variación de su composición botánica no se obtiene facilmente al estudio de una superficie reducida.

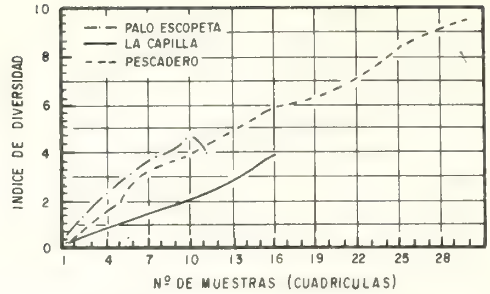

Figura 5.--Indice de diversidad de especies en relación a número de cuadrículas en tres comunidades de Baja California Sur (México).

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Forest Inventory and Landsat MSS Vegetation Mapping for Arizona[1]

J. David Born and Clifford Pearlberg[2]

Abstract.--Forest inventory and a Landsat multispectral scanner vegetation mapping project were combined to produce forest resource statistics and vegetation maps for Arizona. Natural vegetation classes were mapped with ownership, elevation, and slope information. Statistical estimates were made of area, volume, growth, and mortality, by owner group for the State.

INTRODUCTION

The Forest Survey Unit of the Intermountain Research Station, USDA Forest Service, conducts periodic assessments of forest resources in the Rocky Mountain States (fig. 1). These assessments are supported by forest inventories made at approximately 10-year intervals by National Forests, Forest Survey, and cooperating organizations. State, regional, and national publications report the resulting information concerning timber supplies with supporting statistics about forest area, condition, and volume, growth, and removals by owner classes. Recent reports include information about the availability and suitability of forest land for various nontimber uses (USDA FS 1981).

In Arizona the principal cooperator for the 1985 statewide forest survey was the Forestry Division of the Arizona State Land Department (ASLD), with additional support from the U.S. Department of the Interior, Bureaus of Land Management and Indian Affairs, and several Indian tribes. Some National Forests were also included in the survey, although National Forest data in the Rocky Mountains are usually collected independently by the Forests, and the data are aggregated for State level and other analyses.

Aerial photographs are typically used in forest surveys to estimate areas of major forest conditions and to locate field sample sites.

Figure 1.--The Rocky Mountain States.

However, satellite digital data are increasingly being used to assist in making vegetation surveys (Brass, Likens, and Thornhill 1983). The ASLD had developed the capability to process satellite data in the early 1980's and was interested in mapping and describing the vegetation within the State.

A statewide forest survey had not been done since 1962 (Spencer 1966), and volume data for pinyon-juniper, mesquite, and other woodland types had never been collected. Obviously, a new survey was needed. So following a test study in 1982, a cooperative project was initiated in 1983.

[1]Paper presented at the Symposium on Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones. [Tucson, Arizona, October 13, 1987].

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The satellite data for this project covered over 85,000 square miles, or 75 percent of the State. The forest inventory, excluding National Forests, covered over 70,000 square miles, or 62 percent of the State. Areas excluded from both procedures were the Navajo Indian Reservation and Yuma and La Paz Counties, those counties being considered nonforest.

The Forest Survey objective of updating forest resource information for the State was obvious, but the ASLD had additional needs for detailed mapping of vegetation within the State. Ownership, extent, composition, and location of forest and range resources are key attributes needed to carry out responsibilities of wildfire protection and suppression, land management assistance, and insect and disease detection and control. Similar information is also required for the management of nearly 10 million acres of State trust lands.

SATELLITE AND OTHER DIGITAL DATA

Data Sources

Landsat multispectral scanner (MSS) data which are composed of four bands (wavelengths) of digital data--red, green, and two infrared, were used as the primary data source. Five Landsat satellites have been launched since 1972. The last two, Landsat 4 and 5, transmit data for many areas around the globe every 16 days. Twenty-two scenes of data, each covering an area about 115 miles square, were selected for use in the project from the most recent cloud-free summer satellite passes. Digital terrain data, digitized from 1:250,000 scale Defense Mapping Agency (DMA) maps, were also purchased as a source for slope, aspect, and elevation data. Fortunately, a land net database, based on the Public Land Survey System of townships and sections, was available from the Arizona State Department of Transportation, which could be used with some updating and modification.

The final set of digital data needed was an ownership file. Ownership data were available only on maps from various sources that had to be digitized into the land net format--a time-consuming and tedious process. Bureau of Land Management, Forest Service, State, and other maps were used as sources of ownership information, which were reconciled during the digitizing process.

Equipment and Software

Equipment[3] used:
- Prime 9950 Computer with 16 megabytes of internal memory
- Two 300-megabyte disks
- Two 675 megabyte disks
- Versatec electrostatic color plotter
- Two digitizing workstations, including graphics terminals
- Lexidata color image display
- Trilog color printer/plotter
- Zeta 4-pen color plotter

Software used:
- ELAS satellite image processing system developed by NASA-NSTL
- DTAP digital terrain applications package developed in-house
- ARC/INFO map digitizing and modeling geographic information system from Environmental Systems Research Institute
- INFO tabular database management system from Henco Software, Inc.

Procedure

The raw MSS data are composed of sensor elements (pixels) of spectral reflectance data, each representing about 1.1 acres. Each pixel has four reflectance values, with quantization levels ranging from 0 to 255, for each of the four wavelengths, or bands, of data. These reflectance values must be converted into data meaningful in terms of ground classification. Four general steps are required to convert the pixel data into labeled map data. The process is done for one scene at a time because of differences in spectral values caused by the atmosphere, sun angle, and phenology of the vegetation.

Geographic Registration

The digital data are not registered to any map base when received, so a number of control points must be identified in the data and on maps. About 50 points were located for initial control, and the 30 with the lowest locational errors were used. The points are used in a least squares regression analysis, so a new location can be computed for each pixel relative to the respective map. During this process the data were resampled to 50 by 50 m in size, or about 0.6 acres, for data reduction.

Pixel Classification

Pixels must be organized into homogeneous groups that relate to ground conditions. In this case, a procedure called unsupervised classification was used because it works well with natural vegetation. The data were grouped, based on division of the natural spectral range of the data, rather than using statistics files based on training sets from ground truth (supervised classification). An analyst can fine-tune the divisions of the spectral range until the groupings adequately represent the vegetative cover within the scene area.

The data were screened by the criteria, and each pixel was assigned to one of 40 to 50 predefined statistical classes, based on a combined value from the four band reflectance values. The quality of work done in this step and in labeling the classes is the key to the success or failure of MSS vegetation classification.

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[3]Use of trade or firm names is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Class Labeling

Class labeling is assigning names from field conditions to the statistically defined classes, and aggregating those classes that are not significantly different in terms of field conditions. This step requires considerable field work and is critical to the process. Analysts trained in both remote sensing and field conditions are essential for satisfactory class labeling. In this project, the selection of labels was based upon the land cover classes in "The Natural Vegetation of Arizona" (Lowe and Brown 1973). Although these land cover classes could not be reproduced exactly, the differences were insignificant for most uses. The classes used in the project are shown below.

Landcover Types Used in the Forest Survey Project

Agriculture
Agriculture/Desert Woodland
Burn
Chaparral
Chaparral/PJ
Chaparral/Riparian Deciduous
Crops
Crops/Grassland
Desert Shrub
Desert Shrub/Chaparral
Desert Woodland
Desert Shrub/PJ Trans.
Grassland
Grassland/Brush
Grassland/PJ
Grassland/PJ Trans.
Locust
Mesquite
Mesquite Shrub
Mesquite/Oak Brush
Mesquite/Riparian Hardwood
Mining Operations
Mixed Conifers
Mixed Conifers with Crown Cover Codes (1,2,3,4)
No Data
Oak Brush
Oak/Woodland
Oak/Chaparral
Oak/Riparian Hardwood
Oak/Locust
Oak/Juniper
Oak
PJ (Pinyon/Juniper)
PIPO (Ponderosa Pine)
PJ/Chaparral
PJ/PIPO
PIPO/Oak
PJ Pinyon, Juniper with Crown Cover Codes (1,2,3,4)
PIPO Ponderosa Pine with Crown Cover Codes (1,2,3,4)
PJ (Pinyon, Juniper w/no Crown Cover Codes)
PIPO (Ponderosa Pine w/no Crown Cover Codes)
PJ/PIPO Trans.
Riparian Deciduous
Riparian Hardwood
Shadow
Soil/Rock
Urban
Wetlands
Water

Crown Cover Codes

Code	Crown Cover (%)
1	10
2	10-24
3	25-54
4	55-84
5	85-100

Mosaic Scenes

For areas as large as Arizona, the scenes must be combined, or mosaicked, to delineate counties or other areas that cross scene boundaries. The land net, containing the survey system and ownership information, was also overlaid on the final data file. Mosaicking was accomplished by manually matching scene boundaries, as in an aerial photo mosaic, to eliminate overlap.

Digital Terrain Data

The DMA terrain data are used to generate overlays for elevation, slope, and aspect. Conversion software are used to convert the new data into registered elevation slope and aspect overlays. The terrain data could also be used to stratify the data following pixel classification. Here, a decision rule is developed to assist in separation of vegetation conditions with similar spectral "signatures" but occurring at specific elevation levels or physiographic sites. However, this was not done in the project but could be used to improve classifications for future use in local areas.

Products

A great variety of map and statistical summary products can be produced from the final digital database. In this project the digital data products were oriented toward the seven 1/2-minute quadrangle maps and counties. For State and other local applications, the color quad maps, with ownership and topographic overlays, were most useful. For Forest Survey, the county vegetation maps and tabular statistical summaries of area by vegetation class and owner class were required. The statistical area summaries were controlled to known areas by owner and county and were used in expanding the field data taken by Forest Survey crews.

FOREST SURVEY

Design

The statistical sampling design most commonly used by Forest Survey in the Rocky Mountain States is a two-phase sample with estimated stratum

weights. This requires a large primary sample of points, usually from aerial photographs, classified into land and vegetation classes to estimate the area of sampling strata. A smaller set of field samples from each stratum is then measured on the ground to obtain final classifications and estimates of timber volumes, condition, and so forth. A similar design uses acreage summaries of mapped vegetation classifications for strata areas, and MSS data were used in this manner.

The field samples must be identified by strata, and the Universal Transverse Mercator (UTM) Grid System (U.S. Department of Defense 1973) was used to select the samples and locate them in the registered MSS data. The field samples are always on some multiple of a 1,000-m grid. In Arizona the field sample intensity varies from a 1,000-m grid to an overlay of two 10,000-m grids. The intensity was varied to meet the needs of cooperators and to sample field conditions adequately.

The UTM grid system works well with satellite data because it is available anywhere in the world except the polar zones, and it is a square metric grid system. In the northern hemisphere a sample point location is described by first stating the 6-degree longitude grid zone number, followed by the number of meters east of the center of the zone (easting) and then by the number of meters north of the equator (northing). Numbers are always positive because each zone midpoint easting has been given an arbitrary value of 500,000 m east. Conversions to latitude and longitude can easily be made using a simple computer program (Chojnacky and Tymcio 1987).

Field Data

Field data, other than land class, were taken only on forested locations, with present or potential 10 percent minimum stocking of trees. Four kinds of data, as described below, were taken at each field sample location.

Site Classification

Site data include locational, landform soil, use, and vegetation characteristics. Included are observations about past wildlife, livestock, recreational, and timber use. A list of nonlocational data items is shown below. Further information about each of these items can be found in our Arizona field manual (USDA Forest Service 1985).

<u>Site Classification Items</u>

Ground Land Use
Use Trend
Ownership
Stand Origin
Stand Class
Seed Source
Forest Type
Stand Size Class
Percent Crown Cover
Elevation
Aspect/Slope/Curv. Class
Physiographic Class
Primary Habitat Type
Secondary Habitat Type
Field Location History
Local Forest Type Assoc.
Vegetative Concealment
Browsing
Wildlife Use
Grazing Intensity
Livestock Access
People Use
Recreation Use
Trails or Roads
Availability
Litter Depth
Humus Depth
Soil Texture
Soil Group
Percent Bare Ground
Percent Compaction
Soil Erosion
Slope Length
Micro Slope Length
Water Proximity
Water Type
Land Use Impact
Size of Condition
Size of Forested Area
Burn History
Cutting History
Type of Cutting
Distance to Road

Tree Data

Tree measurements were taken for volume, growth, site potential, and present condition. Post and Christmas tree potential are recorded on woodland sites. A list of tree data items is show below. Further information about each item can be found in the Arizona field manual.

<u>Tree Data Items</u>

Tree History
Species
DBH-DRC/EDRC
Height
Radial Growth
Tree Age
Crown Form
Relative Crown Position
CR Ratio Uncompacted
CR Ratio Compacted
Crown Class
Surface Defect
INT Defect-CF
Total Volume Loss-CF
Damage/Cause of Death
Tree/Cover Class
1st I&D Incidence
2nd I&D Incidence
Mistletoe Class
Percent Tree Crown Cover
Maximum Crown Width
Minimum Crown Width
Number of Stems
Posts-Line

Posts-Corner
Christmas Tree Grade

Lower Canopy Vegetation Data

Ground cover percent, when in excess of 5 percent for a species or group, was estimated for shrubs, forbs, and graminoids for each of three height classes. This procedure has been described in detail by O'Brien and Van Hooser (1983).

Visual Tree Segmentation

For woodland sample locations, trees were subsampled for detailed volume measurements for use in constructing volume tables. Further information about this procedure is given by Born and Chojnacky (1985).

Products

Products resulting from the forest inventory field data were individual sample location per acre summaries and a data file containing all original data and generated or computed variables. The per-acre summaries include cubic foot volume, and board foot volume for timber species.

Using woodland growth and segmentation data, regression models were developed to predict growth and volume respectively. From this project, for example, we have constructed the first statewide tree volume equations and tables for mesquite, pinyon, juniper, and oak, based on diameter at ground level and total height (Chojnacky in preparation).

COMBINED RESULTS

The strata areas, or areas by vegetation classes, were used with the field sample data to estimate area, volume, and other characteristics of forested lands. Custom software and the FINSYS (Born and Barnard 1983) data reduction system were used to compile the data into statistical tables. Any variable of interest from the field sample data may be summarized and expanded to the total area sampled. In this project the State was divided into 11 sample areas because of sampling intensity, cooperation, or resource characteristics. The number of statistical tables that could be produced is almost infinite, but we produced about 24 area tables and about 86 tables on volume, number of trees, growth, and mortality. Additional tables for statistical verification and special analyses were also prepared as needed. Tables by owner class and county were generated for a subset of these tables.

Reports

An unpublished report will be forwarded to each of the organizations cooperating in the forest survey or the Landsat analysis of a particular area of the State. A comprehensive report, "Forest Resources of Arizona," is in preparation and will be published in 1988. This report will include statistical tables, a description of the forest resources of the State, and an analysis of the forest resources situation.

Separate publications will include the woodland volume and growth estimation models. These publications will be available from the Intermountain Research Station in Ogden, UT. One paper has been presented concerning mesquite growth and yield modeling (Chojnacky 1987).

Additional information concerning the availability of additional Landsat MSS map products may be obtained by contacting the coauthor at the Arizona State Land Department in Phoenix.

CONCLUSIONS

Although analyses of the data are not complete, we can offer several comments about the results. The Landsat MSS vegetation maps provide a spatial dimension to the project that should be useful locally. However, minor misclassification errors are easy to find, particularly in low-density woodland where the ground vegetation or soil reflects a strong signal. The use of topographic data in separating vegetation classes probably would have helped to discriminate between vegetation types with similar reflectance values.

The vegetation classes used differ somewhat from Forest Survey definitions and thus were probably less efficient statistically than classes designed to meet the definitions. Registration of the field samples into the Landsat data appears to be somewhat of a problem and may be caused partially by the averaging effect of the large pixel size and the resampling to 50 m. However, the estimates resulting from the two-phase sample appear to be unbiased by these problems, although poor registration certainly increases the sampling errors.

The database created by the Landsat and ownership data may be continually updated and is a useful tool for State agencies. The initial work is done, and only the future can tell of the many potential applications of the information.

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Plant Genetic Resources Threatened in North American Deserts: The FLORUTIL Conservation Project[1]

Gary P. Nabhan[2], Wendy Hodgson[3], and Luis Hernandez[4]

Abstract.--Scientists in the U.S. and Mexico are now collaborating on a data bank project named florutil, for the useful plants at risk in the U.S./Mexico border states. Analysis of the information in these dbase III files will help determine which threatened plants have been used directly for such purposes as food, fiber, medicinal, ornamental, etc. products; used indirectly as genetic resources for plant breeding; how these uses affect species distribution and abundance; how land management practices affect the same; whether usefulness serves as an incentive for conservation; and if and where these plants are now protected in situ or ex situ. Focus is presently on rare members of the cactus and agave families found in the four U.S. and six Mexican states.

INTRODUCTION

FLORUTIL is a recently developed project regarding the threatened useful flora of the U.S./Mexico borderlands. It is a progress report on traditional uses and conservation of selected cacti and succulents in the states adjacent to the International Boundary. The contribution of our coauthor on this presentation, biologist Luis Hernandez Sandoval of the Universidad Autonoma de Tamaulipas, as well as the assistance of his colleague, Guadalupe Malda, and our new colleague at the Desert Botanical Garden, Allan Zimmerman, Ph.D. is acknowledged.

One of the raging debates regarding succulent conservation concerns the relative impacts of overcollection versus habitat degradation in threatened rare species. Fortunately, because of the recent careful assessments by Hernando Sanchez-Mejorada, Edward Anderson and Nigel Taylor, we know that 14 of the 23 rarest cacti studied in northeastern Mexico are threatened primarily by commercial collectors rather than by habitat destruction (Anderson, 1987). With regard to FLORUTIL, their study raises additional questions: to what extent is traditional collection and use of succulents by indigenous desert cultures a threat to rarer species? If some of these plants have been gathered for hundreds if not thousands of years by desert cultures, to what extent is this plant gathering responsible for the rarity of these succulents? And how have ancient land management practices affected their habitats relative to the more recent introductions of livestock, trucks, and bulldozers? Finally, does a plant's recognized usefulness encourage its conservation or its overexploitation?

As far as these authors are concerned, the ultimate answers to these questions are still out. Opinions vary, ranging from Jared Diamond's contention that primitive peoples are just as destructive to biodiversity as industrial societies, to ethnographers' claims that cultures with long traditions in one place have developed taboos and other feedback mechanisms to keep from overexploiting rare resources. Yet, in most cases, opinions have been formed more by anecdotes than by systematically-collected information. And in all too many cases, not enough time has been spent with Native Americans to understand how direct harvest of certain plants is related to land use practices, traditional or otherwise. FLORUTIL, then, is an attempt to bridge these gaps, by seeing where the gaps are in our understanding, and trying to fill them by further fieldwork and discussion with known experts.

1Paper presented at the Symposium on Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones. [Tucson, Arizona, October 12-16, 1987].

2Gary P. Nabhan, Ph.D, is Assistant Director at the Desert Botanical Garden, Phoenix, AZ.
3Wendy Hodgson is Herbarium Curator at the Desert Botanical Garden, Phoenix, AZ.
4Luis Hernandez is ethnobotanist/botanist at the Universidad Autonoma de Tamaulipas and Comite Promotor, Tamaulipas.

THE FLORUTIL PROGRAM

FLORUTIL is a set of programs written in dbase III programming language for use by the Desert Botanical Garden in cataloguing information about how people used and continue to use threatened plants found in the borderlands of the U.S. and Mexico. Using this system data about the plants and their uses can be entered and edited and a variety of reports based on this information can be prepared. FLORUTIL was a result of an interest in how ethnobotany and plant conservation biology overlap and interrelate. It also grew out of the recognition that many Mexican ethnobotanists/biologists, in particular Luis Hernandez and Guadalupe Malda, shared the authors' interest and have influenced the emergence of this project. This project is currently funded by a Lindley Foundation grant.

Before data is entered into the computer the information is written out on forms which correspond to the data fields in the program. A data field consists of a question followed by multiple-choice answers. By using these forms references are included. The forms also provide a file for additional data storage which may later prove to be quite important but cannot as yet be entered into the program.

FLORUTIL uses 2 related databases, one called Plants and the other called Uses. The database Plants contains 38 fields each containing information specific to one type of plant. The database Uses contains 19 fields each containing information specific to one part of a plant used by people. These fields with multiple choice answers were jointly conceived by the collaborators of this project and are presented in both Spanish and English.

Those plants considered threatened or endangered in the broad sense, ie., "plants at risk in the borderland states" are initially included. Each plant is then screened for possible uses. Research at present is focusing on the agave and cactus families, which include a significant number of useful and threatened taxa. These families also represent the largest families in the living collections at the Garden and are of primary interest in Garden research. All taxa considered rare will be included eventually.

A problem that arises is when a rare plant is catalogued but there is no information on its use. Yet, information on plant usage exists for other related species or subspecies. The difficulty comes in deciding when to make an assumption that the rare plant was used in a similar fashion as the related species/subspecies. The position taken is generally one of few assumptions made although each plant is taken on a case by case basis realizing data can be added or deleted in the future. Possible mis-information as a result of assumptions made can be explained using as an example Manfreda singuliflora Gentry, a member of the Agave family known from Chihuahua and possibly Sonora. Members of the genus Manfreda are known for there sudsing and cleansing properties produced in the fleshy underground stem (rhizome). Manfreda singuliflora differs from other manfredas in that it does not produce a fleshy rhizome. Thus, one cannot assume it was used for cleansing purposes, nor can it be assumed that it wasn't. In another case, the Seri people are able to differentiate between three different species of barrel cactus (Ferocactus), the flowers and pulp of F. wislizeni (Engelm.) B. & R. being far better tasting and healthier eating than those of F. acanthodes (Lemaire) B. & R. or F. covillei B. & R. (Felger and Moser, 1985). Yet, it is assumed that the roots, fruits, and seeds of Amoreuxia gonzalezii Sprague & Riley were used in similar fashion as the more common saiya, A. palmatifida Moc. & Sesse. However, this assumption is based on scanty evidence and strong gut feelings.

Although data has been entered only since 1 August 1987 the importance of this tool, more specifically, its capability to compile and then later sort on the basis of any number of data elements for report purposes, is realized. For example, according to information entered for the 93 records or taxa, 33% are used for food and of this percentage, 49% are used in a cooked form. Of the total number of taxa entered 54% are negatively impacted by overexploitation, 28% are negatively impacted by livestock herbivory, and 23% are negatively impacted by urbanization. Forty-two percent of the total number of taxa recorded occur in Arizona.

CASE STUDY I

Peniocereus greggii (Engelm.) Britton & Rose var. transmontanus (Engelm.) Backeberg

Peniocereus greggii var. transmontanus, or Arizona queen-of-the-night, offers contradictions in terms with regard to classifying botanical features and its relationship to humankind. This member of the Hylocereae can be considered a geophyte, or a scandant dwarf cactus which may reach 3.5 meters in height. Its lead gray wirey stems often mimic those of Larrea tridentata (DC) Coville, one of its nurse plants, so that it is visually inconspicuous. Yet, on a early summer evening its blossoms are fragrant enough to be noticed from dozens of meters away. It is considered a reasonable candidate (Category 2) (U.S. Fish & Wildlife Service, 1987) for threatened species status in the United States, yet it is widespread throughout its range. It has long been utilized, in a somewhat consumptive fashion, but land conversion may be at least as serious a threat as traditional uses. Finally, its traditional uses bridge the distinction between food and medicine.

This slender night-bloomer has stems frequently no thicker than a finger. Below these dead-looking stems are succulent tuberous roots weighing as much as twenty kilograms or forty-five pounds. Historic notes record the use of flowers, fruit, and the "shoots" as greens (the use of

shoots greens is questionable). But it is the enlarged tuberous roots which serves as the species blessing and curse. Over the last half century, O'odham Indians of the Sonoran Desert have consistently mentioned two major uses of these roots: first, as a food, eaten raw, or baked in ashes, peeled then eaten; second, as medicine, chunked and drunken, or eaten as an aid for digestion, respiratory ailments, headaches, and most importantly, diabetes. Eating the roots of this cactus to control diabetes is of particular interest, for these Pima and Papago people currently have the highest incidence of diabetes mellitus of any ethnic population in the world. This was not true historically, when traditional foods and medicines were ingested in greater proportions than modern store-bought commodities. Nabhan recently collaborated on a nutritional analysis of selected desert foods with Australian chemists. This study confirms that certain traditional O'odham foods formerly protected diabetics from harmful blood sugar variations by slowing the digestion and absorption of meals. It may be that the O'Odham classification and use of night-blooming cereus tuberous roots as both food and diabetic medicine has some empirical validity. These tuberous roots should be given high priority in future analyses for glycaemic responses of foods suitable for diabetic diets.

Ironically, the O'odham knowledge of this plant's potential value was shared with Mexican-American herbalists who purchased so many of these roots that the plants grew scarce in Pima country. Nabhan recently interviewed an elderly Pima man who suggested that this plant was commercially overexploited as a medicine up to 1930 and that it is absent from part of its historic range. Nevertheless, many more references and the authors' observations indicate that land conversion and vegetation destruction for farm development and suburbs have had a severe and lasting impact on queen-of-the-night within the Pima Reservation and in other areas as well.

The O'odham have brought this plant into garden cultivation, in part for the ornamental quality of its fragrant flowers. It is common in botanical gardens, but usually not managed to maintain the gene frequencies of distinct populations. Therefore, at the Desert Botanical Garden both hand pollinations and pollen storage for later use are being attempted in order to maintain distinct but heterogeneous populations of this plant. The Centro Ecologico de Sonora is also involved in a propagation program for night-bloomers. It is worth noting that the species exists in biosphere reserves, national parks, national forests, and wildlife refuges, so that its survival seems somewhat assured.

CASE STUDY II

Ferocactus pilosus (Salm-Dyck) Werderm. and Echinocactus platyacanthus Link & Otto

Based on reports from collaborator Luis Hernandez (pers. comm.) the status of two barrel cacti and their uses are highlighted. Ferocactus pilosus is known as viznaga colorado of the Chihuahuan Desert. Its stems can be solitary, but are often found in massive clumps. It has nine or more uncurved and unhooked spines per areole, erect open flowers, and yellow, dehiscent fruit. Viznaga colorada is found in the heart of the Chihuahuan Desert, including Tamaulipas, Nuevo Leon, extending nearly to Big Bend, Texas, farther north than Nigel Taylor's map shows (Taylor, 1986). Its lemony-tasting acrid fruits are highly favored in Tamaulipas, where they are commonly used as the flavoring for an agua fresca similar to lemonade. In addition, the flower buds are pickled or cooked in various ways as part of the regional cuisine of the Chihuahuan Desert.

And yet neither of these traditional uses deplete the species' populations as much as does the overcollection of the plant as an ornamental for export (L. Hernandez, pers. comm). The commercial trade has restricted its range to more out-of-the-way sites, as highway-sides have been ravaged for years. Transport to U.S., Germany, and Mexico City cactus collectors appears to be the major threat, not food uses.

In the Miquihuana vicinity of Tamaulipas, it is now occasionally used in dulces as a replacement for another barrel with which its range overlaps (L. Hernandez, pers. comm). Echinocactus platyacanthus is more rarely used as an ornamental, but intensively exploited as a food. The stems of this robust barrel are cut, boiled down and prepared as dulces or barrel cactus candy; once the single stem is cut, there is no recovery. Despite ancient use in this manner, northern Mexican population growth has outstripped the slow growth rates of this cactus. Both market use and self-consumption are locally endangering it (L. Hernandez, pers. comm.). Nonetheless, goats do considerable direct damage to the plant where it grows on plains, so that it is becoming more and more restricted to hillsides where agriculture is more scarce. Goats are also likely to trample seedlings and destroy their nurse plants, so that goats may be affecting more than one life stage of this species.

CASE STUDY III

Agave murpheyi Gibson

In 1935 Frederick Gibson, former director of the Boyce Thompson Arboretum in Superior, Arizona described an unusual agave first observed by amateur naturalist William Murphey. Murphey's agave is quite different from other agaves. Of greatest interest are the types of reproduction A. murpheyi is capable of. Unlike other agaves in

Arizona its scape begins to elongate in early winter and continues to grow with warmer weather. Flowers appear in late March and April, some of which may be deformed. At this time bulbils begin to develop. Few capsules and seed are produced. However, bulbils are not the principal means of reproduction, rather the production of pups through rhizome development. (The production of bulbils occurs in other agaves, the most well known being A. vilmoriniana. The authors have recently discovered that following five years of governmental indiscriminate spraying of agent-orange south of Globe A. chrysantha produces bulbils in the inflorescence. This suggests that bulbil formation may be hormonally controlled, at least in part.)

Agave murpheyi appears to be quite rare in the wild. Until the last few years less than half a dozen clones were known. Now, 25 to 30 clones are known, occurring in central Arizona from the Bradshaw and New River Mountains, east to the Sierra Ancha Mountains (R. DeLamater, pers. comm.).All known clones are found in association with archaeological artifacts. There are no documented historic examples of agave cultivation in the U.S. although prehistoric cultivation has been suggested (see Minnis and Plog, 1976; Fish et al., 1985). A terminal spine and marginal teeth recovered from several sites in the Tucson Basin (Fish, et al., 1985) and tissue fragments from La Ciudad excavations (Bohrer, 1986) suggest A. murpheyi was cultivated by the prehistoric inhabitants. Successful establishment of bulbils produced in the inflorescence increases significantly when placed into a disturbed, or cultivated situation (S.Szarek, pers. comm.) Dr. Howard S. Gentry had remarked how the Papago in Sells, Arizona may have cultivated this agave (Gentry, 1982). Indeed, A. murpheyi is a common sight in the government housing area and in most villages on the Reservation it is grown as an ornamental. Laura Kerman, a Papago woman, reminisces how in the days of her grandfather her people harvested large stands of A. murpheyi in a canyon nestled on the west side of the Baboquivari Mountains. Here they lived during the winter months harvesting and pit-baking the cabezas. She was quick to add that her people used the cabezas for food only and, unlike the Mexicans, not exclusively for mescal. It is believed that the population still exists. In Sonora clones have been found at San Luisito and Quitova, an ancient Papago village. At Quitovac Papagos call the plant nonhakam, meaning "it has eggs (progeny)".

Agave murpheyi has favorable characteristics for use as a food source lending itself to cultivation (Bohrer, 1986). If flowers relatively earlier than other agaves, takes less time to mature as compared with other large Arizona agaves, produces large heads for harvesting, and produces bulbils which are easily transported and transplanted. Because it reproduces primarily be vegetative means more uniform plants are produced.

The question of A murpheyi's origin and dispersal is a perplexing one for archaeologist, ethnologist, and botanists. Questions which arise include "were the more northern populations/clones introduced to that area from the south and then tended or cultivated? or "did these more northern populations have their origin through hybridization and introgression via extinct or extant parental species different from the more southern clones and populations followed by tending and cultivation? Plants from northern and southern clones appear morphologically similar and suggests common ancestry and dispersal through trade and travel. This is merely speculative as the question of A. murpheyi's origin requires a great deal of further study.

CASE STUDY IV

Agave potrerana Trelease

Agave potrerana is a very attractive and distinctive agave placed in the group Marginatae (Gentry, 1982). It is non-suckering (does not produce offsets) and produces long tapering glaucous to light green leaves with a conspicuous gray margin. The flowers are densely produced in the upper two-thirds of the spike. They are quite attractive and conspicuous, up to 58 millimeters long and range in color from red to yellow.

The leaves have an abundance of strong fiber, considered longer and more pliable than its commercial relative, A. lechuguilla Torr. of the same general area (Gentry, 1982). According to a local informant in the Sierra Campana region in central Chihuahua A. potrerana was called "lechuguilla", that the fiber was used locally, and it was common all over the area. In 1959 Dr. Gentry observed a large scattered population on the Sierra Campana. But, upon revisiting the area in 1964 he found the plants much scarcer, the range there being heavily stocked with cattle. As noted by Gentry (1982) heavy cropping of the inflorescence by cattle can soon decimate a non-suckering agave population. Cattle impact of this type has also been observed with A. chrysantha Peebles, the rare A. arizonica Gentry & Weber, and the suckering A. toumeyana Trel. var. bella (Breit.) Gentry and A. shawii Engelm. ssp. goldmaniana (Trel.) Gentry. It is probable that other agave species are impacted as well.

Agave potrerana is recognized as a potentially important genetic resource for its strong, long, and pliable fiber, possible high sapogenin content, and freezing tolerance (Gentry, 1982). Yet, it is known from only a handful of collections.

CASE STUDY V

Mammillaria thornberi Orcutt

Clumps of Thornber's fishhook cactus occur over a 6000 square kilometer range in south-central Arizona and adjacent Sonora. The chilito-type fruit have an astringent taste compared to those of sympatric Echinocereus species, and one

Papago man joked to Gary how Coyote hade made it sour. The O'odham names for this species and Mammillaria microcarpa Engelm. refer in some way to their relation with Coyote, such as Coyote's paws or Coyote's hedgehog. Its fruits are casually eaten and the plant is sometimes dug up when found near saguaro-harvesting camps and brought back for cultivation in Papago dooryard gardens. One is planted as part of a holy shrine in a Papago yard.

The species was proposed as threatened and intensively studied when it was learned that the Central Arizona Project's irrigation canal would go through its densest populations. However, in the search and salvage, Frank Reichenbacher and others located not hundreds but tens of thousands of individuals of this plant in or near the canal routes, including sizeable populations within Saguaro National Monument. Nonetheless, the plant cannont be considered "safe" in the Saguaro National Monument vicinity. With remote sensing expert Dr. Michael Parton, Nabhan recently determined that as much as 25 % of this plants habitat in the 275 square kilometer area around Saguaro National Monument has been destroyed over the last fifty years, as suburbs have extended up to the park boundary. Dr. Pete Bennett of the National Park Service cautions that National Monuments themselves are not safe sites, but instead are subject to an intensity of casual cactus collection unparalleled on other state or federal lands. Park Service land managers have inadvertantly contributed to the decline of this species by locating parking lots and restrooms in the midsts of populations opening them to trampling and collecting. Both M. thornberi and M. microcarpa are being damaged at the Monument rest area except where they persist under cholla (Opuntia spp.) nurse plants. On private and state lands, creosotebush removal threatens several populations, for this species has a greater-than-statistically predicted association with creosote as a nurse plant, and shares microrhizae with this shrub. The safest sites for species survival may be on the Tohono O'odham Indian Reservation where massive land development schemes are possible but less likely to occur.

CASE STUDY VI

Pholisma sonorae (Torr.) Yatskievych

Pholisma sonorae is commonly known as sandfood, as its original name, Ammobroma sonorae Torr. suggests. Its native name in O'odham, hia tadk, means dune root, and the underground inflorescence stalk of this parasitic plant are superficially root-like. However, its haustoria penetrate the roots of other species, primarily Tiquilia spp. and obtain their moisture therein. Sandfood was first obtained for science while an explorer watched native peoples gathering it to eat. Its use, however, may have been referred to as early as 1694, when Juan Mateo Manje encountered along the Sea of Cortez "poor people who lived by eating roots of wild sweet potatoes, honey, mesquite beans, and other fruits" (Karns, 1954). These people, the Hia Ced O'odham, or In-the-Dunes People, have had a particularly rich relationship with sandfood. Some other Papagos nicknamed them the Dune Root Crushers and either an acid in the plant or associated sand grit gave most of them worn down teeth. Although Yatskievych (1985) doubts it, Lumholtz (1912) maintained that these Dune Root Crushers could find the plant out of season, before it broke ground surface. Although it appears to have been a major food source for these small semi-nomadic bands, none of the historic observers claimed that they overexploited it, perhaps because their population densities were so low. To the contrary, the Indians themselves claim that once they stopped using it regularly, plant populations delined. Perhaps their digging of plants when some had seed on them allowed for less random dispersal back closer to the host plant roots. Perhaps their gathering encouraged seed dispersal to safe sites or vegetative branching. Empirical studies to confirm or deny these hypotheses are lacking. In fact, knowledge of how to germinate this plant is lacking. Despite attempts in the 1930's to propagate and can it for Desert Indians, no one has succeeded in successful propagation. A dissertation was once attempted on germinating this species, and only one seed out of hundreds sprouted but quickly died (Cothrun, 1969).

Currently, sandfood is under considerable pressure in a significant portion of its 6000 square kilometer range, due to off-road vehicles and agricultural clearing on both U.S. and Mexico sides. It will, however, persist several years following land clearing and cropping in agricultural fields. It is not, however, a "plant with weedy characteristics" as one U.S. Fish and Wildllife Service from California suggested to Nabhan. One small protected area on BLM land in California does not make this species "safe". Much more study is needed of its population biology. There is an attempt to fill this void with a recent seed collection in cold-storage at the Desert Botanical Garden. In addition, the Cocopah. Quechan, and other tribes of the Colorado Delta need to be asked further about this plant.

CASE STUDY VII

Amoreuxia gonzalezii Sprague & Riley

Amoreuxia is a small genus within the Cochlosperm family and is comprised of four species. All are herbaceous perennials arising from a more or less woody tuber-like root. It is an attractive genus, with deep green leaves and large yellow-salmon flowers. Its distribution ranges from northern Mexico and adjacent U.S. states through Central America to Peru. The common species, A. palmatifida Moc. & Sesse., commonly called saiya or temaqui, takes in the majority of the distribution of the genus. Amoreuxia gonzalezii appears quite rare.

Little is known of A. gonzalezii although its more common relative, A. palmatifida, has figured prominently in the diets of many native people in Arizona, Baja California, Sonora, and possibly throughout much of Mexico and Central America. At Onavas, Sonora, ethnographer Campbell Pennington (1980) remarked how the people there utilized both saiyas but whether they differentiated between the two species is unclear. The roots were the most important plant part used, eaten raw, boiled, or more commonly roasted. The immature and mature seeds, immature fruits, and even the flowers were, and continue to be used for food. At the Universidad de Sonora research has begun to economically develop A. palmatifida for its nutritional products obtained form the root.

Amoreuxia palmatifida and A. gonzalezii are very similar in appearance. However, the fruits of A. palmatifida are globose and its seeds are kidney-shaped whereas fruits of A. gonzalezii are more attenuate and its seeds are globose. Unfortunately, the few collections made of saiya in general are of those usually in flower and do not include fruits. Possible reasons for this are the conspicuousness and attractiveness of the flowers and invertebrate and vertebrate herbivory, including cattle, on the immature fruits. Thus, because of few and inadequate specimens the true picture of the distribution and utilization of A. gonzalezii is very unclear. At present this saiya is known with certainty from only two collections in the U.S., (in the Santa Rita and Patagonia Mountains) and four from Mexico, three in Sonora and the type locality in northern Sinaloa. It may occur in Baja California based on a collection and description by T.S. Brandegee 21 years before the plant was described. The plant appears to be more abundant in southern Arizona (J. Kaiser, pers. comm.) and northern Sonora (R. Felger, pers. comm.) but specimens must be collected for documentation.

Up until now, saiya seeds have been difficult to germinate. Ethnographer Homer Aschmann (1959) remarked how central Baja Californians found it difficult to germinate the seeds of A. palmatifida back in the 1940's. However, they may have encouraged root production by regularly disturbing the soil. At the Desert Botanical Garden propagator Patrick Quirk is now growing over a dozen A. palmatifida and four A. gonzalezii following scarification of the seed. Propagation studies and intensive field work to better document A. gonzalezii will continue.

SUMMARY

The goals of FLORUTIL are four-fold, 1) to encourage U.S./Mexico collaboration on ethnobotany and conservation, 2) identify economic, ecological, and cultural benefits of plants now threatened, 3) identify areas where useful threatened flora can be protected, and 4) analyze how various uses and land management practices affect endangerment. The area involved is one of great diversity, biolgically and culturally, taking in four U.S. and six Mexican states. Over three-fourths of the area has a semi-arid or arid climate and 17 vegetation provinces are represented.

FLORUTIL will also identify which threatened plants are useful as 1) food, fiber, medicine, etc. without industrial processing, 2) new potential suppliers of chemicals or products for industry, and 3) genetic resources for crop improvement of horticultural and agricultural domesticates. Some extremely rare species have been traditionally utilized by local inhabitants of the desert, and yet there is little understanding of their impact on the population biology of these useful resources. Because of that, it is hoped that those who have studied these species in the field offer their perspective on the threats to these species, and the status of traditional versus commercial uses. If it is found that some rare species have been well-studied, next year's fieldwork will be concentrated on others that are poorly known.

FLORUTIL will also identify which useful threatened plants are currently protected 1) by native plant laws regulating collection and habitat destruction, 2) in situ, within biosphere reserves, sanctuaries, or areas designated critical habitat, and 3) ex situ, in botanical gardens, seed banks, and experiment stations. Ultimately, we hope you can use our results as well as contribute to them. Today, fueled by concerns raised in the FAO, UNESCO, and IUCN, conservationists are considering land reserves for endangered species which will also serve as sanctuaries for threatened cultures, where they can persist in their traditional hunting, gathering, and farming practices, but where logging, mining, or industrial agriculture will not be allowed. The Biosphere Reserve concept includes, not excludes, cultural uses of native plants. We hope that our data analyses will answer a number of questions relating to locating and managing such biosphere reserves.

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Conservation and Development of Food and Medicinal Plants in the Sierra Tarahumara, Chihuahua, Mexico[1]

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Abstract.--Objectives and preliminary results are presented for a project in the Sierra Tarahumara (northern Sierra Madre Occidental) of Chihuahua, Mexico. The endemic dry-season edible green ("quelite"), Thelypodiopsis byei (BRASSICACEAE), of the deciduous subtropical forests of the barrancas and the medicinal roots, "chuchupate" (Ligusticum porteri, APIACEAE) and "matarique" (Psacalium decompositum, ASTERACEAE), are of local and national importance. Ecological characterization of natural populations and cultivation are underway in order to prevent the extinction of these economically important herbs as well as to enhance their contemporary role in the diet, health care and commerce of the Tarahumara Indians.

INTRODUCTION

The Sierra Tarahumara, which includes the mountains and western barrancas, is located in the the Dry Domain Ecoregion of the Sierra Madre Occidental of northwestern Mexico (Bye 1983). The dominant indigenous group in the region is the Tarahumara Indians who exploit a number of native edible and medicinal plants for local consumption as well as for trade (Bye 1981, 1985, 1986; Mares 1982; Pennington 1963). Certain locally restricted plants play a critical role in the season diet, indigenous health care and local commerce as well as national and international markets (Linares & Bye 1987). Changing land use practices and increased consumer demands threaten these limited vegetal resourses with local extinction. In order to avoid the loss of these plants as well as to enhance their value in the Tarahumara economy, we have initiated a program of conservation and commercialization of selected species.

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STUDY AREA

Western Chihuahua is classified as the **Dry Domain** Ecoregion (Bye 1983, modified from the U.S. Forest Service Ecoregion classification of Bailey 1978). The climate of the eastern foothills and the mountains is described as cool semiarid **(BSk)** while the upper western slopes are said to be semiarid subtropical (Cwa) (Schmidt 1973).

Southwestern Chihuahua is inhabited by the Tarahumara Indian and mestizo populations. During the last 10 to 15 years, the dominant Mexican economic forces associated with improved communication and transportation services have entered the region and are altering the socioeconomic-ecological system. With these changes, the roles of certain wild and managed plants have shifted. In particular, certain plants have decreased in abundance due to overcollecting, principally by outsiders to the local communities.

OBJECTIVES

The purpose of this project is to select a few pilot plants and develop techniques for their management in conjunction with Tarahumara participants. The benefit will be three-fold: 1) the plants will not become locally extinct;

2) the local inhabitants will have a supplementary source of income as well as food and medicinal plants; and 3) the demand from local, regional, national, and international markets can be met.

ACTIVITIES

For each selected plant, the preliminary phase of this project includes: population ecology and habitat description of natural populations; geographic distribution; economic importance in the local, regional and national markets; germination test; introduction of plants into cultivation; and native habitat preservation.

The techniques to be developed will complement the existing empirical practices currently being used by the Tarahumara. In the selected cases, experimental work in the field and in the Jardin Botanico will bypass those barriers that the Tarahumara have not been able to overcome. These barriers include: unreliable seed/propagule production; uneven seed germination; poor asexual propagation. The techniques devised will be of a simple and inexpensive nature that after training, the Indians will be able to carry them out independently.

The first year (initiated in February of 1987) consists of: 1) making local contact with Tarahumara inhabitants (via meetings, individual visits and "tesguinadas" (social-political activities associated with cooperative work and corn beer consumption)); 2) discussing the project and soliciting suggestions from ejidal and Tarahumara officials and school personnel; 3) locating, documentating and characterizing of natural plant populations; 4) collecting of seeds and roots for _in situ_ and _ex situ_ studies of reproductive characteristics of the plants; and 5) establishing contact with the State of Chihuahua's commission for the coordination of development in the Sierra Tarahumara.

During the second year (1988), demonstration areas will be established on ejidal land as a prelude to pilot cultivation plots. Educational programs for children will be conducted through the schools. Demonstrations for adults will be carried out in each area. First year activities will continue.

The final year (1989) will initiate the pilot cultivation gardens. The educational programs as well as seeds will be targeted at groups who were the most responsive during the previous year. In the case of plants with commercial value, we will link the Tarahumara with potential national consumers such as the Mexican public health sector and Mexican industries. The introduction of the cooperative concept may be important in order to ensure adequate production and distribution of the plant products (in this case roots).

Project activities of the barranca are centered in Barranca de Batopilas, Municipio de Batopilas, with Tarahumara from the Quírare/Huimayvo region. In the sierra, two project areas are located in Ejido de Cusárare, Municipio de Guachochic, and in Ejido San Ignácio Arareco, Municipio de Bocoyna.

LOCAL COLLABORATION

The active participation of Tarahumara Indians at the individual as well as ejido levels is imperative for the success of the project. To date various individuals have collaborated through: 1) loan of land and housing; 2) information on past collecting activities and location of natural populations. Meetings with ejido officials indicate that different parcels of land for experimental plantings will be available in 1988. Officials from public (Secretaria de Educación Publica, Zona Tarahuara) and private (Jesuit) schools have agreed to participate in horticultural programs of the Jardín Botánico, UNAM, by providing course time and garden plots in different areas starting in 1988.

Because the benefit of this project will be best measured in the long run, we feel that it is important to stimulate the children in the area of horticulture. Traditional Tarahumara practices include small scale cultivation of plants of special interest. Unfortunately, this tradition is disappearing rapidly due to the infiltration of contemporary materialistic value systems. Reinforcement of native practices of plant management as well as demonstration of potential economic benefit could determine the success of the project.

FOOD PLANTS

Wild and semi-domesticated plants continue to play an important role in the Tarahumara diet. Because of the contrasting precipitation patterns,

certain dry season and early rainy season plants are critical sources of vitamins and minerals as well as limited vegetable protein in the basic maize-bean-squash-chile diet.

The target food plant for this study is Thelypodiopsis byei Rollins (Tarahumra: "mekwásare") of the BRASSICACEAE. It is an endemic annual of the western canyons and grows only during the dry season (December - June). It reproduces by seeds. Other wild mustards are perennial and grow during the rainy season.

The Tarahumara value it as an edible fresh leafy green (Spanish: "quelite") because it is the only native vegetable available during the dry season. In recent years, this wild mustard has declined. With the increased demand for meat to feed the construction workers during the 1970's and 1980's, cattle and goat herding increased dramatically in the area. Being one of the few green plants in the area, it is over grazed by the animals. Only a few isolated pockets of the herb exist today.

Seeds will be gathered and cultivation techniques developed so as to increase the plant. The Tarahumara have their empirical process of "quelite" cultivation (Bye 1979). This project complements that process by increasing the seed for wider distribution. The immediate benefit will be the greater availability of an edible herb adapted to the local dry conditions.

Other plants designated for future studies include:

Agave pacifica Gentry (A. angustifolia Haw. sensu lat.) AGAVACEAE
Pacific or blue maguey of the western barrancas provides edible flowers and is the basis of local alcohol production ("pistol").

Stenocereus thurberi (Engelm.) Buxb. CACTACEAE
The sweet spineless (at maturity) cactus fruit ("pitaya") is a dry season product of the colmnar cactus of the western canyons. The Indian and Mexican peoples are very fond of this sweet fruit for which they often pay more per kilo than that of cultivated fruits.

Opuntia sp. CACTACEAE
An unidentified pricklypear ("tuna"), known from one Tarahumara ranch in the semi-arid oak forests of the upper barrancas, produces a small, yet very flavorful (strawberry-pineapple) fruits in June and July.

MEDICINAL PLANTS

Among the Tarahumara Indians as with other indigenous Americans, there is no clear cut distinction between edible and medicinal plants. Herbs, roots and barks serve to maintain one's health and are not seen as sources of calories or pharmaceutical substances. The medicinal plants included in this study are not only consumed locally but also have a great and every increasing demand on the national and international scales.

The target species of the project are two medicinal roots that will become very important in the immediate future. Chemical, pharmacological and clinical studies have demonstrated certain levels of efficacy. Recent examples of guayava leaves (Psidium guajava L.) or burn tree bark ("tepezcohuite", Mimosa tenuflora Benth.) have shown what publicity about proved or demonstrated effectiveness can do to increase the demand and deminish the supplies of medicinal plants that have caught the public's attention. The following plants are under current clinical study and have captured public interest. We anticipate a dramatic increase in the demand and subsequent over collection of the plants. Because of their limited distribution in Mexico, irrational exploitation of natural populations could lead to their extinction. Controlled collecting of wild populations as well as harvesting of cultivated plants can assure adequate and reliable supplies as well as economic income for Tarahumara.

The first target species is Ligusticum porteri C.&R. (sensu latu) of the APIACEAE. Locally known as "chuchupate", this perennial herb is found in the pine-oak forests and produces an oderiferous, resinous rootstock. The roots are highly prized through out Mexico and are imported into the USA as a medicinal plant (Bye 1986; Linares & Bye 1987). It is used by both the Tarahumara and the Mexicans to alleviate stomach aches and to suppress coughs. Pending final approval, the Mexican national health program (Instituto Mexicano del Seguro Social) plans to introduce it as an official medicine plant for treating gastric ulcers of patients in rural and urban clinics under the name "angélica" (X. Lozoya, personal communication).

The popularity and effectiveness of this root has greatly increased the demand for it. Known in Mexico only from the mountains of Chihuahua and adjacent areas, it is marketed widely through out

Mexico. Over the past 10 years, this once readily available remedial root is offered only sporatically. The retail US dollar cost per kilogram of dried roots in the Mexico City market has increased from $3.48 in 1978 to $17.77 in 1987. Herb vendors and collectors have indicated that it is now very rare and the quantities are unpredictable. In the Mercado Sonora, the largest medicinal plant merket in Mexico, it was no longer available as of September, 1987.

The second target species is Psacalium decompositum (Gray) H. Robins. & Brett. of the ASTERACEAE. "Matarique" is a perennial herb restricted to the mountains of western Chihuahua and adjacent regions. The finely threaded roots are prized for alleviating gastrointestinal and rheumatic pains (Bye 1985). Through out Mexico it is valued as a diabetes remedy and tinctures of it are sold in the USA (Linares & Bye 1987).

As in the case of "chuchupate", the plant has gained popularity and has become overcollected as the new roads open up the mountains. Many local populations are now extinct. The demand in Mexican markets has dramatically increased to the point that it too is sporadically available. The retail US dollar price per kilogram of dried roots in Mexico City's Mercado Sonora rose from $8.33 in 1978 to 16.60 in 1987.

Another important medicinal plant which faces similar threats and which may be studied as part of the project in the near future is Hintonia latiflora (Sess. & Moc. ex DC.) Bullock of the RUBIACEAE. The bark of "copalquín" prized for relieving fevers and body pains (Bye 1986).

CONCLUSIONS

This initial report outlines the target species of food and medicinal plants restricted to the Sierra Madre Occidental of northwestern Mexico. Because of their restricted distribution and economic importance coupled with anthropogenic factors which threaten the existence of natural population, a project is underway to save the species. Cultivation of the plants, in particular the medicinal roots, not only provides an alternative source of vegetal material for commerce but also can generate economic income for the indigenous population while relieving collecting pressure on wild plants.

Rather than propose a preservation policy for these plants, we believe that it is beneficial to increase the interaction between the plants and the Tarahumara. Thus, the plants will develop more under human management and the people (of the region as well as those outside) will place a greater value on them -- and thus manage them better.

The Tarahumara have valued these plants and have "managed" them to a certain extent. However, they have not been able to respond quickly to the increased demand. The drastic rate of plant population reduction has been caused by increased demands generated by intense forces foreign to their past experiences. By combining the traditional Tarahumara plant management techniques with those of western science, certain barriers to rapid plant propagule regeneration can be removed. With more plants available for distribution, the Tarahumara can cultivate them and use them locally or move them through established marketing systems.

The conservation concept is based upon two important ethnobotany points: 1) effective conservation of plants can be achieved by increasing the positive interaction between plants and people, and 2) the people from whom the plants and information originated should benefit directly from the results of field and laboratory studies.

ACKNOWLEDGMENT

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INTRODUCCION AL ESTUDIO DE LAS PLANTAS ALIMENTICIAS DE BAJA CALIFORNIA SUR[1]

Heriberto Parra H.[2]

Resumen.- Este trabajo rescata y sistematiza la información sobre el - uso y utilización de las plantas alimenticias silvestres del estado de Baja-California Sur en México según las utilizaban los Guaycuras y Pericúes nativos de esa región así como los colonizadores de la época post-misional.
En base a una exhaustiva revisión bibliográfica y a encuestas personales, se generó un catálogo de 106 plantas alimenticias que comprenden a 57 géneros - de 30 familias en las que sobresalen por su importancia Cactaceae y Mimosa--ceae. 30 de estas especies resultaron ser las más importantes y profusamente utilizadas representando el 27% del total.
Se concluye que las plantas alimenticias de Baja California Sur revisten vital importancia como nuevas fuentes potenciales de alimentación para consumo humano y que sus características de adaptación y resistencia a la sequía las convierten en valioso germoplasma para usos agronómicos que podrían generar-nuevos cultivos de bajos requerimientos de agua adaptados a las zonas áridas.

INTRODUCCION

El acelerado desarrollo tecnológico de las últimas decadas, ha incrementado y mejorado a un grado - superlativo el rendimiento de las cosechas, con el - fín de cubrir las demandas de una población mundial que se multiplica vertiginosamente, sin embargo, -- desde tiempos históricos, no se ha inducido al cultivo ninguna nueva especie, se puede decir que todos los cultivos alimenticios y de fibras actuales ya - eran accesibles al hombre primitivo.

Se estima que de las 350,000 especies vegetales que existen en la tierra (1), solo entre 1000 y 2000 han tenido importancia económica para el hombre y de éstas solo 15 especies proveen los alimentos que le permiten su sobrevivencia.

Según Felger y Nabhan (2), son 7 las especies - principales que sostienen a la humanidad, estas son: trigo, arroz, maíz, cebada, soya, frijol común y papa, las cuales exceptuando el arroz han tenido su - orígen en zonas semiáridas. Los restantes cultivos básicos no rebasan algunas docenas, aspecto importante si se considera que en el mundo se calcula - que existen 30,000 especies de plantas alimenticias siendo 3,000 las que potencialmente representan -- fuentes importantes de alimentación.

Desafortunadamente los cultivos antes mencionados son genéticamente vulnerables a plagas y enfermedades tradicionales y ninguna muestra adaptación a las zonas áridas y semiáridas (2), que cabe aclarar, representan dos terceras partes de la superficie de la tierra; ésto nos demuestra la gran - necesidad de contar con cultivos adaptados a esas-condiciones de aridez, para así poder introducir - la agricultura a estas grandes superficies del globo terrestre y de esta forma coadyuvar a la creciente demanda de alimentos principal fuente de energía para el hombre.

En contraposición a los siete cultivos principales antes mencionados, existe una gran diversidad de plantas alimenticias que habiéndose adaptado a - las zonas áridas, han constituido por miles de años, la base de la alimentación de los indígenas de los desiertos (2). Estas especies podrían inducirse al cultivo utilizando una diversidad de nichos ecológicos en zonas áridas y semiáridas con mínimos requerimientos de agua y energía. Para maximizar la

[1] Ponencia presentada en la Reunión sobre Estrategias de clasificación y manejo de vegetación silvestre para la producción de alimentos en zonas áridas.

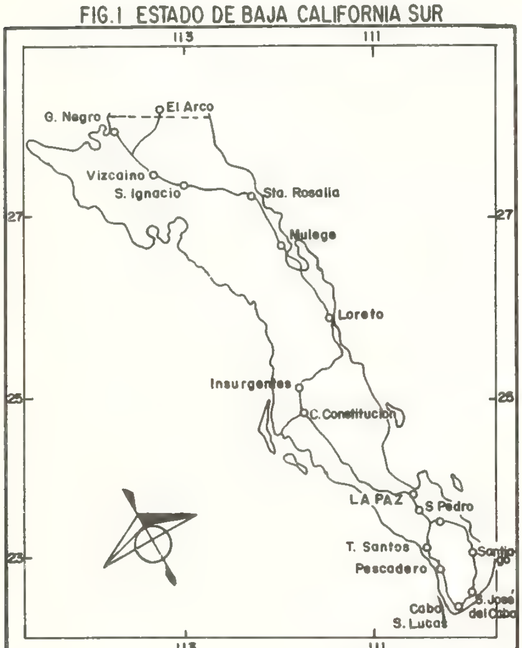
[2] Ing., Director del Centro de Investigaciones - Forestales y Agropecuarias; La Paz, Baja California Sur, México.

productividad y minimizar los costos, estos nuevos cultivos deberán desarrollarse adáptandolo al medio ambiente y no tratando de modificar al medio ambiente para adaptarlo al cultivo (3).

El objetivo principal de este trabajo es dar a conocer la importancia que tienen las plantas - alimenticias silvestres de Baja California Sur, a través del rescate del conocimiento popular y de - la información dispersa en relación al uso y utilización de estas plantas para el consumo humano.

Para lograr dichos objetivos se recurrió a una exhaustiva revisión bibliográfica, entrevistas personales y observaciones de campo, este trabajo se realizó en el estado de Baja California Sur (figura 1) en el lapso correspondiente de 1979 a 1984.

FIG.I ESTADO DE BAJA CALIFORNIA SUR



A. Plascencia Favila

REVISION DE LITERATURA

No existen estudios etnobotánicos sobre el estado de Baja California Sur a excepción de la in-- formación al respecto reportada por los misioneros españoles, por este motivo se mencionan como referencias, algunos de los resultados de estudios etnobotánicos y ecológicos realizados por Felger, Moser y Nabhan en el denominado desierto Sonorense.

El desierto Sonorense (figura 2) lo constituyen 310,000 km^2 que albergan 2,500 especies de - - plantas que producen semillas (4). Felger y Nabhan (3) reportan que el 18% de esa flora ó sea 450 especies (375 especies nativas y 75 especies naturalizadas), fueron utilizadas profusamente por diferentes nativos de la región.

Más del 10% de esas 375 especies alimenticias han sido utilizadas como fuentes importantes de alimentación.

Una relación similar se encuentra en las plantas utilizadas por los indios Seris de Sonora, quienes habitaron una parte del desierto Sonorense.

Cuando menos 80 especies de esta región, mas - del 15% del total de esa flora, se sabe que han sido utilizadas como alimento por los Seris y más del 10% de éstas (8-10 especies) fueron las fuentes principales de su alimentación. (5).

Algunas de las características más importantes de estas plantas de las zonas áridas y semiáridas - son las siguientes: gracias a su evolución, han logrado adaptarse plenamente a las condiciones extremas del medio ambiente. Las plantas efímeras germinan rápidamente al haber húmedad disponible en el - suelo: su ciclo vital se completa en una sola estación o incluso antes, éstas evitan la sequía prolongada permaneciendo latentes como semillas por largo tiempo,

Las plantas perennes como los cactus, resisten las sequías debido a sus tejidos suculentos, algunos árboles o arbustos la resisten porque pueden aprovechar el agua del subsuelo y en general, gracias a diversas adaptaciones, almacenan agua y reducen su pérdida por transpiración.

FIG. 2 LOCALIZACION DEL DESIERTO SONORENSE

S. Arredondo R.

Estudios recientes muestran que las plantas - de los desiertos pueden multiplicar al máximo la - energía alimenticia de sus semillas y tubérculos - (2). Las semillas de estas plantas son con frecuencia de menor tamaño que sus homológos de zonas - - templadas o tropicales, pero ésto no los hace inferiores como alimentos, antes al contrario se ha demostrado con el frijol que el tamaño de la semilla es inversamente proporcional al valor proteinico - (6).

Esta energía nutritiva concentrada es una de- las características de las zonas áridas que las hacen ideales como plantas alimenticias. Otra característica importante es su alta capacidad fotosintética. (7).

A pesar de no conocer su antiguedad, la presencia de las pinturas rupestres de Baja California Sur, nos demuestra que el hombre primitivo (8). Aunque no se ha determinado con exactitud la fecha de la entrada del hombre a la península, se le ha- asignado una antiguedad mayor de 7,000 años a algunos "concheros" (montones de conchas formadas por los indígenas al consumir los mariscos del golfo - de California (9).

La población de la región propiamente peninsular, hoy desaparecida debido a la introducción de- enfermedades europeas, se formaba de tres grupos - linguísticamente diferentes pero culturalmente semejantes: de norte a sur, los Cochimíes, Guaycuras y Pericúes. (figura 3).

FIG. 3 REGIONALIZACION DE LOS GRUPOS ETNICOS EXTINTOS

FUENTE: PABLO L. MARTINEZ (1956) HISTORIA DE BAJA CALIFORNIA

G. Becerra M.

Dichos grupos eran neolíticos, seminómadas -- que vivieron de la caza, pesca y recolección de -- las semillas y frutas comestibles sin los beneficios de la agricultura, los animales domésticos, - la cerámica y la vivienda permanente; la homogeneidad cultural se debía a la adaptación absoluta al medio ambiente. Esta adaptación se manifestó en - dos formas, la alimentación y elaboración de necesidades materiales relacionados con la adquisición de alimentos, el vestuario y la vivienda, utilizando elementos minerales, vegetales y animales.

Debido a la total desaparición de estos indígenas, la única información disponible sobre el - uso de las plantas alimenticias de esos días, es- la que dejaron en sus escritos los misioneros, entre los que destacaban Miguel del Barco, Juan Jacobo Baegert, Miguel Venegas, Francisco Javier Clavijero y el padre Piccolo entre otros, habiéndose perdido mucho de ese conocimiento y sabiduría al - no haberse perpetuado de generación en generación.

MATERIALES Y METODOS

La metodología de este trabajo consistió en - la determinación de las plantas alimenticias y el conocimiento de las características del desierto - Sonorense, Baja California Sur y Todos Santos, para lo cual se recurrió a revisiones bibliográficas, entrevistas y observaciones de campo.

Un considerable porcentaje de la metodología consistió en una exhaustiva revisión bibliográfica, la cual se realizó en tres diferentes niveles, uno que abarca la región denominada desierto Sonorense y que nos permitió fundamentar y enmarcar el trabajo en el contexto etnobotánico regional. Una segunda revisión bibliográfica sobre Baja California Sur que nos permitió ubicarnos a nivel estatal y finalmente una tercera etapa más específica sobre la zona de Todos Santos, que fué donde se llevaron a cabo así mismo las entrevistas y observaciones.

Se realizaron 30 entrevistas en el poblado de Todos Santos y rancherias aledañas, así como 10 más entre residentes de la ciudad de La Paz originarios de la zona de Todos Santos.

Las observaciones de campo consistieron en la localización de las plantas y la verificación de - la información obtenida en las entrevistas.

RESULTADO Y CONCLUSIONES

Con el presente trabajo se rescató y sistematizó la información que sobre el tema se encontraba dispersa y se concluye que los Cochimies, Guaycuras y Pericúes utilizaron profusamente las plantas alimenticias y que la poca información al respecto es la que reportaron los misioneros en sus escritos.

Que fueron los mismos españoles quienes cambiaron los hábitos alimenticios de los indígenas, los cuales acabaron por desaparecer por completo a causa de las enfermedades introducidas por los españoles. Con ellos desapareció el más completo conocimiento de las plantas alimenticias y sus usos.

Los rancheros a pesar de esa pérdida de conocimiento, aprendieron de nueva cuenta y por experiencia propia, a usar paulatinamente las plantas alimenticias. Es importante mencionar que tanto indígenas como rancheros llegaron eventualmente a coincidir en el uso de las mismas plantas para los mismos propósitos.

Se remarca que estas plantas alimenticias se caracterizan por tener simultáneamente otros usos tales como forrajes, medicinales, industriales, para construcción, artesanal, ornamental, etc.

Así mismo se concluye que se detectaron 106 especies alimenticias en Baja California Sur que corresponden a 57 géneros de 39 familias y sobresalen en importancia por el número de especies, las familias Cactaceae, Amaryllidaceae y Mimosaceae, habiendo sido altamente significativo Cactaceae con 8 géneros y 27 especies.

De esas 106 plantas alimenticias, 30 especies fueron las más importantes y profusamente utilizadas en la región de Todos Santos desde antes de la ocupación misional y representan el 27% del total, a continuación se describen:

PLANTAS ANUALES Y EFIMERAS

Familia AMARANTHACEAE

"Quelite" (*Amaranthus watsoni*) Standley

De esta especie, al igual que *A. palmeri*, se tuestan sus semillas y se comen en pinole ó atoles; así mismo sus retoños tiernos son cocidos o guisados en múltiples formas.

Familia CHENOPODIACEAE

"Chual" (*Chaenopodium fremontii*) S. Wats.

Las semillas se tuestan y se muelen, los retoños tiernos crudos, cocidos ó guisados como si fueran quelites.

Familia PORTULACACEAE

"Verdolaga" (*Portulaca oleracea*) L.

Las semillas de éstas se tuestan y se comen en pinole ó atole, los retoños tiernos crudos se utilizan en ensalada ó bien cocidos en múltiples formas.

RAICES, TUBERCULOS Y BULBOS

Familia COCHLOSPERMACEAE

"Saiya" (*Amoreuxia palmatifida*) Sesse & Moc. ex. D.C.

Los tubérculos se consumen crudos, cocidos en caldo o bien tatemados ligeramente; asimismo, las flores y frutos tiernos son comestibles.

Familia POLYGONACEAE

"San Miguel" (*Antigonon leptopus*) Hook & Arn.

Las semillas se tuestan hasta que revientan y se muelen para hacer una harina. También se consume el tubérculo tatemado ó cocido.

Familia EUPHORBIACEAE

"Caribe ó mala mujer" (*Cnidosculus angustidens*) Torr.

Las semillas se tuestan y se comen. El tubérculo se consume tostado ó cocido.

Familia CONVOLVULACEAE

"Jicama" (*Exogonium bracteatum*) (Cav).Choisy

Se comen los tubérculos crudos, los cuales contienen mucha agua.

ARBOLES Y ARBUSTOS

Familia AMARYLLIDACEAE

"maguey" (*Agave spp.*)

De sus pencas, cabeza y pedúnculo, una vez asados, se obtiene un producto que fué muy apetecido por los indios; las flores exudan miel que puede ser aprovechada; asimismo las semillas se muelen para la elaboración de harina.

Esta especie constituyó uno de los alimentos básicos de los nativos pobladores de la región.

Familia SAPOTACEAE

"Bebelama" (Bumelia occidentalis) Hemsl.
Los frutos se comen crudos ó en conserva.

Familia SOLANACEAE

"Chiltepín silvestre" (Capsicum annum var. baccatum).

El fruto se utiliza crudo como condimento - y saborizante en diversos platos; asimismo se pueden emplear en curtidos de gran aceptación en la- cocina mexicana.

Familia CAESALPINACEAE

"Palo verde" (Cercidium microphyllum) (Torr.) Rose & Jhtn.

Las semillas de esta especie se tuestan y se muelen cociendose en agua las vainas verdes se pueden comer crudas o cocidas asimismo las flores.

Dentro del mismo género Cercidium floridum - "dipúa", también se emplean las vainas y semillas tostadas y molidas, con las cuales se elabora una harina y se come como atole.

Familia ANACARDIACEAE

"Ciruelo cimarrón" (Cyrtocarpa edulis) (Brandegee) Standley.

De esta especie, abundante en la región del- Cabo, se utilizan sus frutas crudas, las cuales - tienen un sabor agridulce que sirve para apagar - la sed; también se consumen en almíbar o en curtidos. Las semillas crudas y tostadas llamadas chuniques también son un alimento apetecido a manera de golosina, ya que poseen un sabor parecido a la nuez.

Familia EBENACEAE

"Guayparín" (Diospyros californica) (Brandegee) I. M. Jhtn.

Los frutos se comen crudos ó cocidos en almíbar.

Familia MORACEAE

"Salate" (Ficus brandegee)Standley y (F. palmeri) S. Wats.

Los frutos pueden ser ingeridos crudos o en almíbar. Las semillas tostadas y molidas también tienen propiedades alimenticias.

Familia VERBENACEAE

"Orégano" (Lippia palmeri) S. Wats.

Las hojas desmenuzadas sirven para condi- - mentar un sin número de alimentos. Principalmente empleadas en la cocina Italiana y Mexicana.

Familia ASCLEPIDACEAE

"Talayote" (Matelea cordifolia) (A. Gray) Woodson.

El ejote se puede comer crudo ó guisado de diferentes maneras ó bién en escabeche.

Familia PINACEAE

"Piñón" (Pinus cembroides) Zucc. var. (lagunae) Passini.

Las semillas pueden ser comidas crudas ó tostadas o bién molidas para hacer pasteles, poeen un alto poder enérgetico por su contenido de proteínas y aceites.

Familia MIMOSACEAE

"Mezquite" (Prosopis juliflora)

Las semillas en vaina se tuestan y se muelen; con la harina resultante se pueden hacer panes. -- Las vainas crudas sazonadas también son consumidas para apagar y calmar la sed.

Familia FAGACEAE

"Encino" (Quercus spp)

La semilla es la parte comestible; se pueden ingerir crudas o tostadas; asimismo se puede elaborar con la harina de éstas un atole.

Familia RUBIACEAE

"Papache" (Randia megacarpa) Brandegee

Los frutos se comen crudos ó en mermelada.

Familia BUXACEAE

"Jojoba" (Simmondsia chinensis) (Link) schneider.

La semilla cruda ó tostada se considera como sustituto de café asimismo se puede preparar champurrado mezclado con leche, también se pueden elaborar galletas, mezclando la pasta de la semilla - molida y tostada mezclada con harina de trigo.

Familia TURNERACEAE

"Damiana" (Turnera diffusa) Willd.

Sus hojas y ramas tiernas son ampliamente utilizadas para la preparación de una infusión muy popular, el "té de damiana"; asimismo se elabora con élla un licor muy apreciado.

Familia LILIACEAE

"Yuca" (Yucca valida) T. S. Brandegee

Se comen los pétalos de la flor cocidos y guisados de diversas formas. Los frutos pueden comerse crudos ó cocidos en almíbar.

PALMAS

Familia ARECACEAE (Palmae)

"Palma de abanico" (Washingtonia robusta) Wendl
Los frutos poseen muy poco mesocarpo, sin embargo, la corteza está rodeada de una sustancia azucarada de sabor agradable. Las semillas se pueden moler para hacer harina. El corazón ó palmillo puede ser ingerido.

CACTUS

Familia CACTACEAE

"Biznaga" (Ferocactus spp)
Los botones y las flores se comen cocidos. Los frutos se comen crudos ó en almíbar. La pulpa del tallo sírve para elaborar dulce, cubierto. Las semillas molidas también pueden ser ingeridas.

"Pitaya dulce" (Lemairocereus thurberi)(Engelm) Britt. & Rose.
El fruto de esta especie fué el más importante y apreciado de las poblaciones indígenas, es también el que más popularidad tiene hasta la fecha. Su fruto se come crudo ó bien puede ser secado, en las rancherías se cuece hasta alcanzar una consistencia de pasta que se puede conservar por largo tiempo.

"Pitaya agria" (Machaerocereus gummosus)(Engelm) Britt. & Rose.
El fruto de esta especie se come crudo ó seco. Asimismo por un proceso de fermentación sírve para hacer vino.

"Cholla"(Opuntia cholla) Weber
La parte comestible es el fruto, el cual se come crudo y los retoños tiernos, se pueden ingerir a manera de nopalitos.

"Nopal" (Opuntia spp)
Las pencas tiernas guisadas de diversas formas tradicionales. Los frutos se comen crudos ó cocidos hasta hacer una pasta.

"Cardón" (Pachycereus pringlei) (S. Wats) Britt & Rose.
La parte comestible de este cactus es el fruto, el cual se come crudo. Sus semillas fueron muy apreciadas por los nativos de la región. También se puede elaborar vino.

De estas 30 especies, 20 que representan el 66.6% siguen utilizándose con bajos niveles de importancia y principalmente por los integrantes de las rancherías y pequeños poblados, llegando al mercado de La Paz, capital del estado, solamente pitaya dulce, orégano, damiana y en algunos casos ciruelas cimarronas. Las 10 restantes que representan el 33.3% han caido en desuso, sin embargo fueron alimentos importantes de los indígenas.

Aunque los rancheros sudcalifornianos saben que las plantas reportadas son alimenticias escasamente las utilizan, debido a motivos de carácter económico, social y cultural. El principal limitante para un consumo constante y sostenido de estos alimentos es la estacionalidad de los mismos y que en su gran mayoría solo se encuentran disponibles en y después de la época de lluvias.

Con los resultados de este estudio se está puntualizando la posibilidad de diversificar las dietas alimenticias del sudcaliforniano principalmente en áreas rurales.

En otro orden de ideas se concluye que las plantas alimenticias de Baja California Sur, revisten vital importancia como nuevas fuentes potenciales de alimentación para el consumo humano, que sus características de adaptación y resistencia a la sequía están afines a la realidad ecológica de la región y las convierte en plantas generadoras de germoplasma para usos agronómicos y perspectivas de domesticación, lo cual podría generar eventualmente nuevos cultivos de bajos requerimientos de agua adaptados a las zonas áridas y semiáridas.

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PRODUCCION COMERCIAL DE CACTACEAS AMENAZADAS EN ZONAS ARIDAS

Guadalupe Malda[1] y Jorge Jiménez[2]

Resumen.- La sobrecolección de algunas cactaceas ha disminuido considerablemente sus poblaciones naturales. En un vivero ejidal piloto se capacita a los campesinos para que propaguen y comercialicen el recurso. Se practican técnicas de reproducción vegetativa y sexual. Para determinar la colecta de propágulos, se evalúan poblacionalmente las especies.

INTRODUCCION

El impacto de la actividad humana sobre el medio ambiente ha hecho resentir a las poblaciones de plantas y animales a tal grado que una gran porción se encuentran en peligro de extinción.
En el caso de las plantas, las especies más afectadas son las de lento crecimiento o poca potencialidad reproductiva; las especies endémicas o bien las que son explotadas comercialmente sin que exista un plan de manejo adecuado.

Una de las causas por las que ciertas especies se encuentren amenazadas por extinción es la magnitud de los saqueos de ejemplares silvestres en sitios con una riqueza florística considerable pero con alto grado de endemismo.

Entre los casos más dramáticos tenemos como ejemplo que en 1980 salieron del país 1300 ejemplares de la cactácea <u>Ariocarpus agavioides</u> y cerca de 6000 del género <u>Pelecyphora</u> ; ambas plantas endémicas de Tamaulipas. En 1987 aún siguen saliendo ilegalmente plantas amenazadas, como sucedió en el caso de la expedición de un permiso ilegal que permitía la salida del país de una tonelada de semillas de cactáceas, todas endémicas de Tamaulipas.
Obviamente, saqueos de esta magnitud impiden la recuperación de las poblaciones naturales.

Al hacer una revisión de los listados de plantas en peligro de extinción, publicados por la Unión Internacional para la Conservación de la Naturaleza, por el instituto Nacional de Investigaciones sobre Recursos Bióticos y por Texas Organization for Endangered Species, hemos encontrado que para el Noreste de México se tienen reportadas entre 70 y 90 especies amenazadas por extinción, 60% de las cuales son cactáceas.

Lamentablemente, dichos reportes difieren mucho entre sí debido a que no hay información suficiente ni estudios específicos al respecto. Una gran parte de las especies reportadas en estos listados están agrupadas en la categoría indeterminada, lo que quiere decir que no se sabe el estado real de las poblaciones en el campo.

Como se mencionó anteriormente, gran parte del problema se debe al tráfico ilegal de estas plantas. Esto representa un grave problema socioeconómico para los habitantes de las zonas áridas, ya que la comercialización de cactus, aunque sea ilegal, constituye una fuente de ingresos económicos a los campesinos, por lo que prohibir su venta resultaría una medida bastante drástica e inútil.

Por otro lado, una de las actividades realizadas por los habitantes de zonas áridas es el aprovechamiento de algunas cactáceas comestibles, como la biznaga o el pitayo. Sin embargo, esto se hace sólo mediante la extracción de ejemplares silvestres.

CREACION DEL VIVERO PILOTO.

El presente trabajo propone un plan de propagación de cactáceas amenazadas ornamentales, así como de algunas comestibles, con la finalidad de que el campesino obtenga ingresos económicos y al mismo tiempo proteja el recurso.

La zona de trabajo está ubicada en el suroeste del Estado de Tamaulipas, en el Ejido La Reforma, Municipio de Jaumave. Consultando con los habitantes de la zona se nos otorgó un terreno de media hectárea

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(ver foto 1), para la creación de un vivero. Al mismo tiempo, se organizó una comisión entre los campesinos para encargarse del establecimiento y

Foto 1. Vista del terreno para el vivero.

mantenimiento del vivero, hasta la fecha esta comisión la forman dos ejidatarios dedicados de tiempo completo al trabajo.

Como primer paso, se procedió a delimitar el terreno con cercas vivas de pitayo (*Stenocereus* sp.) y garambullo (*Myrtillocactus geometrizans*), con el objetivo de que dentro de algunos años los habitantes locales puedan cosechar frutos para autoconsumo sin tener que caminar largos trechos (ver foto 2).

Foto 2. Cerca viva de pitayos.

Posteriormente se iniciaron las labores de acondicionamiento del terreno, nivelando el suelo en los sitios donde este se pierde a causa de las lluvias. Se hizo una limpieza de la vegetación del terreno, respetando los árboles y arbustos nativos, para que posteriormente se utilicen como sombreaderos naturales. También se están construyendo sombreaderos artificiales con material regional, donde se acondiciona el suelo para formar camas de siembra.

La selección de las especies para propagar se hizo de acuerdo con los siguientes criterios:

1) Las especies reportadas en peligro de extinción para la zona.
2) Las especies que sufren un mayor saqueo por los comerciantes ilegales.
3) Las especies seleccionadas por los campesinos.

De esta manera, las especies amenazadas ornamentales escogidas fueron:

Mammillaria carmenae
Mammillaria albicoma
Mammillaria candida
Obregonia denegrii
Astrophytum myriostigma
Ariocarpus trigonus

Por otro lado, las especies comestibles que serán propagadas en el vivero son el pitayo (*Stenocereus* sp.) y la biznaga (*Echinocactus plathyacanthus*).

EVALUACION DE POBLACIONES SILVESTRES.

Para la colecta de semillas, propágulos y plantas madre, previamente se realiza una evaluación de las poblaciones naturales cercanas a la zona de trabajo.

Dicha evaluación consiste en un análisis poblacional en el que se toman en cuenta los factores que a continuación se mencionan:

1.- Ubicación de las poblaciones.
2.- Area ocupada por la población.
3.- Cantidad de agrupaciones de plantas (en el caso de cactáceas de hábito cespitoso).
4.- Número de plantas en flor.
5.- Número de plantas con fruto.

De cada localidad, se muestrea el 10% de la población, tomando los siguientes datos:

- Número de individuo por grupo.
- Area ocupada por grupo.
- Tamaño en diámetro por individuo.
- Número de plántulas.

Es muy difícil en cactáceas determinar las edades, por lo que para hacer el análisis de los datos poblacionales se procederá a categorizar a los individuos por su diámetro. De esta manera es posible agrupar el número de individuos por cada categoría, y conocer la densidad y distribución espacial por categoría.

Con este análisis y con los datos de floración y fructificación será posible conocer los aspectos fenológicos de las especies, y así poder determinar el número de semillas y propágulos que se pueden colectar en el campo sin afectar la regeneración natural de las poblaciones.

Por otro lado, el análisis poblacional servirá como base para conocer el estado real del grado de extinción en que se encuentran las especies.

La evaluación poblacional se comenzó con Mammillaria carmenae, encontrándose hasta la fecha dos localidades. La primera consta de una población muy pequeña de apenas 17 individuos, 4 de los cuales son plántulas. Esta localidad es saqueada constantemente, con la colecta preferente de plantas pequeñas.

La segunda localidad no ha sido saqueada hasta la fecha, encontrándose 40 agrupaciones de plantas. Muestreando el 10% de la población se ha notado que las plantas que crecen aisladas son de un diametro mayor que las que crecen en grupos. En los recorridos hechos durante los meses de mayo y junio se encontró que todas las plantas con 2 cm. de diámetro o más estaban fructificando, representando aproximadamente el [illegible]% de la población muestreada.

PROPAGACIÓN.

Por el momento, mientras se realiza la evaluación con todas las demás especies, se están colectando algunos individuos como plantas madre, de las especies Mammillaria candida, Ariocarpus trigonus, Astrophytum myriostigma y Obregonia denegrii. Estas especies se ven seriamente afectadas por la erosión de suelos en época de lluvias; por lo que es frecuente encontrar las plantas con la raíz totalmente descubierta.

Este hecho es el criterio que se usa para la colecta de plantas madre, de tal manera que solo se recogen plantas desenterradas para integrarlas al vivero.

El mantenimiento de las plantas madre se hace en los sombreaderos naturales (ver foto 3). Para esto, se limpió el espacio que cubrían la sombra de árboles y arbustos presentes en el terreno; se removió el suelo y se limitó esta área con empedrado. Cada sombreadero se rodeará con malla de gallinero para proteger de predadores a las plantas madre.

Foto 3. Sombreaderos donde se mantienen las plantas madre.

En estos sombreaderos ya han floreado y fructificado una buena cantidad de plantas, de donde se están tomando las semillas para la propagación sexual.

Las camas de simbra para la reproducción por semilla están diseñadas para conservar temperatura y humedad constantes. El suelo que se utiliza es el mismo de la zona, y el único tratamiento que se da es el tamizado.

Con las pruebas de germinación realizadas hasta la fecha, hemos notado que el porcentaje de germinación es mayor con las semillas recién tomadas del fruto en comparación con semillas almacenadas.

Con respecto a la propagación vegetativa se trabaja con dos técnicas:

Corte de brotes.

A las plantas del género Mammillaria se les está forzando la producción de brotes mediante la aplicación de fertilizante; y parece ser que sí hay respuesta favorable.
Posteriormente, los brotes producidos son cortados y se les aplica enraizador combinado con fungicida. Una vez enraizados los brotes, se colocan en camas de siembra para su crecimiento. Finalmente, cuando las plantas adquieran el tamaño adecuado, serán transplantadas a las parcelas en el vivero.

Las pruebas de corte de brotes hechas con Mammillaria carmenae, Mammillaria candida y Mammillaria albicoma han resultado satisfactorias, notándose un crecimiento más rápido de plantas obtenidas por brote que por semilla.

Injertos.

Se están construyendo camas de siembra bajo sombreaderos de material regional para poner a crecer algunas cactáceas columnares como Stenocereus spp., Echinocereus spp. y Myrtillocactus spp.. Estas plantas serán utilizadas como patrón para realizar los injertos, especialmente de plantas dañadas de su raíz o de las cactáceas que no producen brotes.

Cabe mencionar que las pruebas de propagación que hemos hecho hasta el momento han sido a nivel laboratorio. Una vez acondicionadas todas las instalaciones rústicas en el vivero, se capacitará a los campesinos para que ellos mismos realicen la propagación de las cactáceas.

Las plantas producidas en el vivero se destinarán principalmente para su venta. Para esto, se están iniciando los trámites necesarios para desarrollar el sistema de venta legal.

Se escogerán algunas plantas de aspecto vigoroso, producidas en el vivero, para reintegrarlas a su habitat, en poblaciones que presenten menos presiones

de amenaza.

Finalmente, se pretende difundir a otras areas de la zona arida este tipo de trabajo, utilizando el vivero piloto del ejido La Reforma como demostracion de lo que se puede hacer para conservar los recursos vegetales de zonas áridas.

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EVALUACION DE LA VARIACION EN FORMAS DE NOPAL (*OPUNTIA* SPP) TUNERO EN LA ZONA CENTRO DE MEXICO[1]

Eulogio Pimienta Barrios[2], Adriana Delgado Alverado[3] y Ricardo Mauricio Leguizano[3]

La evaluación de las poblaciones de nopal tunero silvestre y cultivado en la zona Central de México, reveló la existencia de unagran variación. Esta variación se expresa en términos de la morfología de cladodios y frutos, época de maduración del fruto, color y peso del fruto, proporciones en los componentes del fruto (cáscara, pulpa y semillas) y composición química de la pulpa del fruto y las semillas.

INTRODUCCION

En la Zona Centro de Mexico se encuentra una amplia variación en formas de nopal tunero. Estas se encuentran distribuídas en tres tipos de nopaleras: silvestres, de solar y cultivadas. Esta variación se expresa en aspectos de: morfología vegetativa (cladodios) y reproductiva (flores y frutos) (Peralta, 1983); fenología reproductiva (épocas de floración y maduración de frutos) (Pimienta et al., 1986); proporción de componentes del fruto maduro (cáscara, pulpa, semilla) (Delgado, 1985; Mauricio, 1985) y composición química de la pulpa y la semilla (Delgado y Pimienta 1987). En este artículo se presenta una forma conjunta los resultados de estas evaluaciones, además se discutirá la importancia que representa esta variación en el potencial futuro de aprovechamiento del nopal tunero.

MATERIALES Y METODOS

El presente trabajo se llevó a cabo durante los años 1984, 1985 y 1986 en 23 municipios localizados en los estados de Zacatecas, Aguascalientes, San Luis Potosí, Jalisco y Guanajuato. La metodología que se utilizó se describe a continuación.

Selección de Localidades, Nopaleras y Plantas

En la selección de localidades se utilizó la cartografía de CETENAL y el conocimiento personal adquirido a través de entrevistas con personas de experiencia en el área de estudio. La selección de nopaleras se realizó a través de recorridos de campo, apoyándose en los siguientes criterios: en el caso de las silvestres, fueron seleccionadas aquellas que presentaban abundancia de plantas y que se encontraba en explotación por las poblaciones circunvecinas. En el caso de las de solar, se seleccionaron aquellas que contaban con variación en formas y que además los propietarios mostraban disposición para proporcionar información. Para la selección de las cultivadas se consideraron los siguientes aspectos: superficie cultivada, disponibilidad de los propietarios, así como la importancia de la producción que se obtiene.

Toma de Datos

En las nopaleras seleccionadas se registraron los siguientes datos: nombre de la localidad, tipo de nopalera, origen de material vegetativo, altitud, período de floración y maduración de los frutos, manejo, sanidad, mercado y comercialización.

En cada nopalera seleccionada se identificaron plantas representativas de la población, en las que se colectaron 20 frutos que se utilizaron para evaluar las siguientes variables: peso del fruto, peso de la porción comestible (pulpa) y no-comestible (cáscara y semillas).

En la pulpa se evaluaron los siguientes compuestos químicos: porcentaje de sólidos solubles totales; azúcares totales (Dubrois et al., 1956); azúcares reductores (Somogyi, 1952); vitamina 'C' (Freed, 1966; Loeffer y Ponting, 1942) y Clorofila

[1]Ponencia presentada en la Reunión de Estrategías de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas (Tucson Arizona, Octubre 12-16, 1987)

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(Arnon, 1949).

RESULTADOS

En el Cuadro 1 se presenta una relación de formas de nopal tunero, que representa la variación registrada en períodos de maduración en el área de estudio. Esta relación revela que el período potencial de cosecha de frutos en los tres tipos de nopaleras, se extiende por un período de 8 meses (mayo-diciembre). Sin embargo, en las nopaleras cultivadas este período se reduce a 4 meses (julio-octubre), lo cual es aparentemente debido a que la mayoría de las formas que producen frutos con características aceptables para el consumo fresco, maduran frutos durante este período.

Cuadro 1. Períodos de maduración de frutos en formas de nopal tunero.

Nombre Común	Período de Maduración de Frutos
Tapón de Mayo[2]	Mayo-Junio
Pachona[2,3]	Julio
Chapeada[1,2]	Julio-Agosto
Reyna[1]	Julio-Agosto
Naranjona[1]	Agosto
Pelón-Liso[1,2]	Agosto
Amarilla[1,2]	Agosto-Septiembre
Blanca-Cristalina[1]	Agosto-Septiembre
Calabazona[2]	Agosto-Septiembre
Cardona[3]	Agosto-Septiembre
Fafayuco[1,2]	Septiembre-Noviembre
Bola de Masa[2]	Octubre-Noviembre
Cascarón[3]	Octubre-Noviembre
Charola[2]	Noviembre-Diciembre

[1]Forma colectada en nopalera cultivada

[2]Forma colectada en nopalera de solar

[3]Forma colectada en nopalera silvestre

A pesar de que existe una amplia variación en formas de nopal tunero, se observa que la producción comercial se apoya en el uso de nueve formas de nopal tunero (Cuadro 2).

Además de la variación en aspectos de fenología, se registró también variación en el peso de los frutos y sus componentes. En el Cuadro 3 se presenta una relación de formas representativas de esta variación.

Un aspecto importante que surge del Cuadro 3, es el hecho de que el peso mayor del fruto y la porción comestible se registró en frutos colectados en nopaleras cultivadas; los pesos menores se registraron en frutos colectados en nopaleras silvestres. En las nopaleras de solar se registraron valores intermedios.

La evaluación de componentes químicos de la pulpa, reveló que el porcentaje de azúcares oscila entre 12 y 17%; en la mayoría de las formas, un porcentaje alto de estos azúcares son reductores. La evaluación del contenido de vitamina 'C', reveló que el valor más alto es de 41 mg/100g y el menor de 8.1 mg/100g. Con excepción de la forma 'tapona', los valores más altos de vitamina 'C' se registraron en formas que producen frutos con pulpa de color verde-claro. En los frutos con pulpa de color rojo y amarillo, se registraron los contenidos más bajos. Se encontró también, que en los frutos color verde claro se sintetiza y acumula el pigmento clorofila; este pigmento imparte un sabor desagradable a los frutos.

Cuadro 2. Formas de nopal tunero utilizadas en nopaleras cultivadas en la Zona Centro de México.

Nombre Común	Estado Productor	Período Maduración
Alfafayucan	México Hidalgo Guanajuato	Julio-Agosto
Chapeada	Zacatecas Jalisco San Luis Potosí	Julio-Agosto
Amarilla	Guanajuato Aguascalientes Zacatecas	Julio-Septiembre
Naranjona	Jalisco Zacatecas	Agosto
Pelón-Liso	Guanajuato San Luis Potosí	Agosto
Blanca Cristalina	Guanajuato Zacatecas	Septiembre-Octubre
Burrona	Zacatecas Jalisco	Septiembre-Octubre
Blanca de Castilla	Aguascalientes Zacatecas	Septiembre-Octubre
Papantón	Zacatecas	Septiembre-Octubre

La evaluación del porcentaje de

aceite y proteína en las semillas, reveló también la existencia de variación. Sin embargo, es importante resaltar, que los porcentajes más altos de aceíte y proteína, se registraron en semillas de frutos colectados en nopaleras silvestres y los menores en cultivadas.

Cuadro 3. Variación en el peso del fruto y sus componentes en formas de nopal tunero.

Nombre Común	Peso fruto (g)	Peso porción comestible (g)	Peso porción-no comestible (g)	
			cáscara	semilla
Cristalina[1]	239.5	152.0	79.3	7.9
Pepinillo[1]	190.6	106.9	77.2	6.6
Blanca[1]	178.9	95.5	76.3	4.6
Calabazona[2]	174.9	102.8	65.5	6.1
Fafayuco[2]	166.5	77.0	81.5	6.5
Blanca Castilla[1]	147.5	75.1	67.5	5.9
Amarilla[1,2]	143.0	79.3	59.8	3.9
Chapeada[1,2]	128.7	62.8	61.1	4.8
Camuesa[2]	128.4	72.6	50.3	5.4
Pelón[1,2]	116.1	58.7	52.3	5.1
Charola[2]	89.5	42.2	44.6	2.7
Pachona[2,3]	61.4	29.4	29.7	2.3
Cardona[3]	59.5	19.7	38.1	1.7

[1]Forma colectada en nopalera cultivada
[2]Forma colectada en nopalera de solar
[3]Forma colectada en nopalera silvestre

Cuadro 4. Variación de componentes químicos de la pulpa en formas de nopal tunero.

Nombre Común	Azúcares (%) Totales	Azúcares (%) Reductores	Vitamina 'C' (mg/100g)	Clorofila total (ug/g)
Serrana[1]	17.2	8.7	41.0	2.8
Camuesa[2]	16.4	10.9	16.4	0.0
Chapeada[1]	16.3	10.3	22.4	4.4
Apastillada[1]	16.0	9.0	9.8	4.6
Fafayuco[1]	14.1	4.7	34.6	2.1
Cardona[2]	13.9	6.1	8.1	0.0
Papantón[1]	13.9	8.9	20.3	6.9
Pelón-Liso[2]	13.8	8.4	16.5	0.0
Naranjona[3]	13.2	8.6	24.2	0.0
Pepinillo[1]	12.4	9.1	19.3	4.4

[1]Frutos con pulpa de color verde-claro
[2]Frutos con pulpa de color rojo
[3]Frutos con pulpa de color amarillo

El análisis de la composición de ácidos grasos en el aceite de las semillas, reveló que los principales ácidos grasos son: linoleíco, oleíco, palmítico y esteárico. De estos ácidos el linoleíco, es el que ocurre en mayor porcentaje (Cuadro 6).

Cuadro 5. Porcentajes de aceíte y proteína en semillas de frutos de formas de nopal tunero.

Nombre Común	Aceite (%)	Proteína cruda base seca (%)
Tapón[3]	20.0	8.6
Cascarón[3]	16.2	10.7
Bola de Masa[2]	15.4	8.2
Fafayuco[2]	14.4	8.3
Redonda[2]	14.4	8.3
Cardona[3]	14.2	9.3
Pachón[3]	11.6	8.5
Chapeada[1,2]	10.6	8.8
Cristalina[1]	10.1	7.1
Amarillo[1,2]	9.8	8.6
PelónLiso[1]	8.4	8.8
Burrona[1]	6.4	6.2

[1]Fruto colectado en nopalera cultivada
[2]Fruto colectado en nopalera de solar
[3]Fruto colectado en nopalera silvestre

Cuadro 6. Composición de ácidos grasos en el aceíte de semillas de frutos en formas de nopal tunero.

Nombre Común	Acido graso (%) Linoleíco	Oleíco	Palmítico	Esteárico
Roja	77.3	12.9	8.9	0.7
Chapeada	74.9	14.9	8.9	1.1
Blanca	74.5	13.7	10.5	1.3
Pelón-Blanco	70.7	14.1	14.9	0.9
Mazuda	68.9	15.9	14.9	0.7
Apastillada	68.7	18.1	14.3	0.9
Calabazona	67.3	17.3	14.4	0.9
Pachona	66.7	14.1	10.2	1.1
Cardona	61.1	23.4	13.2	2.4
Tapona	59.8	22.2	15.6	2.4

DISCUSION

Los resultados de este trabajo revelan que en la Zona Centro de México existe una amplia variación en formas de nopal tunero, que se refleja en la variación de períodos de maduración, peso de frutos, color de la pulpa, proporción de componentes del

fruto maduro (cáscara, pulpa y semilla) y la composición química de la pulpa y la semilla. Un aspecto importante de la distribución y localización de esta variación, lo constituye el hecho de que en las nopaleras de solar se registró la variación más abundante, ya que en estas se registraron formas que se encuentran en nopaleras silvestres y cultivadas.

Los resultados de esta evaluación revelan que en las nopaleras cultivadas y de solar las formas utilizadas producen frutos, que son superiores en peso y calidad a los registrados en frutos de nopaleras silvestres. Esto sugiere que las formas que se han acopiado en las nopaleras de solar y cultivadas, son el resultado de un proceso de selección empírica practicada por los campesinos de las zonas áridas en las poblaciones nativas. El hecho de que las nopaleras de solar son más antiguas que las cultivadas, permite sugerir que las formas seleccionadas inicialmente fueron acopiadas en nopaleras de solar, principalmente para satisfacer necesidades de autoconsumo familiar. Posteriormente, a partir de estas poblaciones se llevó a cabo una segunda selección de fenotipos que se utilizaron para establecer las nopaleras cultivadas. Sin embargo, aparentemente esta selección fue más rigurosa debido a que además de aspectos de calidad del fruto se consideraron otros atributos, especialmente los relacionados con su capacidad de adaptación a condiciones ambientales adversas que prevalecen en las zonas áridas, e.g. sequía, heladas, daños por animales silvestres y aspectos relacionados con el proceso de comercialización, e.g. forma y tamaño de frutos, resistencia de los frutos al manejo durante la cosecha, embalaje y transporte.

Los resultados de la evaluación de la composición química del fruto ('tuna), revelan que desde el punto de vista nutrimental es comparable a otros frutos que comunmente se utilizan para obtener diversos tipos de subproductos e.g. jaleas, mermeladas, alcoholes, vinagres, colorantes, aromatizantes (Brutsch, 1984; Delgado, 1985).

Las partes no-comestibles del fruto (cáscara y semillas) son también susceptibles de aprovechamiento industrial. En el caso de las semillas, los porcentajes de aceíte y la composición de ácidos grasos, indican que este es similar a los aceites comestibles de soya y cártamo (Cigala, 1979; Delgado, 1985); además la pasta que se obtiene de la extracción del aceíte, se puede utilizar como forraje (Cigala, 1979). La cáscara por ser un tallo modificado (Pimienta y Engleman, 1985), puede ser utilizada para obtener pectinas y colorantes.

Se ha generado tecnología para el aprovechamiento agroindustrial de componentes químicos del fruto, la que es factible adoptar en proyectos de aprovechamiento agroindustrial del nopal tunero. Algunos ejemplos son: obtención de nectares, mermeladas y jaleas(Cruz, 1981); aceite comestible (Cigala, 1979); colorantes alimenticios (Valadez et al., 1978); proteína microbiana (Paredes, 1976), pectinas (Mind et al., 1975, citado por Sawaya et al., 1983). También se han registrado evidencias de potencial de uso medicinal de las partes vegetativas (cladodios) y reproductivas (flores y frutos) del nopal tunero (Meyer y Mclaughin, 1981).

El nopal tunero potencialmente representa una alternativa valiosa para las zonas áridas, siempre y cuando en proyectos futuros de explotación comercial extensiva se considera el aprovechamiento integral de la planta.

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DIAGNOSTICO DE LA PAPITA GUERA (*SOLANUM* SPP) EN EL ALTIPLANO POTOSINO ZACATECANO, MEXICO[1]

Soledad Hernández Jabalera[2]

Resumen.--La papita güera es una especie silvestre que se aprovecha como alimento en el centro de México. En las entrevistas realizadas, se detectó que su población ha disminuido, que existen diferentes especies y que han sido pocos los intentos de los productores por sembrarla.

INTRODUCCION

El incremento en la densidad de población y las condiciones difíciles de producción en la zona árida de México, nos obliga a considerar los recursos que potencialmente contribuyen a resolver la demanda de alimentos. La papita güera -- Solanum spp. es una especie silvestre que se ha recolectado tradicionalmente y que forma parte de la dieta de la población rural del Altiplano Potosino Zacatecano en el norte-centro de México. Esta especie se caracteriza por su capacidad de adaptación a los factores climáticos adversos de esta zona, y además posee otras características - como: sabor agradable y contenido protéico de -- 3.2% (Galindo, 1982); considerado más alto que el reportado para la papa común (Solanum tuberosum), y es resistente a plagas y enfermedades.

El objetivo del presente trabajo fue capturar información sobre el conocimiento y la utilización de la papita en esta región. Este trabajo forma parte del proyecto Domesticación de la Papita Guera (Solanum cardiophyllum y S. enhrenbergii).

REVISION DE LITERATURA

La papita forma parte de la flora del Altiplano Potosino Zacatecano; el cual está ubicado en la zona árida y semiárida de México (Luna 1983), se le conoce como: papita güera, papita de monte, papita loca y papita de barbecho. Esta especie es colectada para consumo o bien para venta en los - mercados locales y la colecta se realiza después de la cosecha del maíz hasta el barbecho del siguiente ciclo (Galindo 1982).

Una cualidad importante de la papita es su resistencia a la sequía; ya que se ha logrado obtener producciones en localidades con precipitaciones muy bajas, (42.7 mm)(Otero, Pimienta y Rocha 1986). Galindo (1982) reporta que en Aguascalientes se sembró maíz y papita asociados, y después de una fuerte sequía sólo hubo producción de papita güera.

Respecto a su manejo Martínez (1984) menciona que si bien no existe una selección de tubérculos para sembrar, la gente deja en el terreno tubérculos que permitan su repoblación.

MATERIALES Y METODOS

El trabajo se inició en 1983, en la región del Altiplano Potosino Zacatecano, parte de los estados de Aguascalientes, Jalisco y Guanajuato, situados entre los 21° y 23°de latitud norte y los 101° y 103° de longitud oeste; en clima es de tipo BS y la precipitación es de 310 a 430 mm. La información aquí presentada se obtuvo con base en - entrevistas dirigidas a productores de maíz y frijol bajo temporal y fue ésta la única base para seleccionar los informantes. Se realizaron dos entrevistas; la primera fue con el fin de detectar puntos de interes en la utilización de la papita (exploratoria) y con la información obtenida se planteó la segunda entrevista (formal). Las entrevistas cubrieron los siguientes aspectos: a) Existencia de la planta en el terreno, con la finalidad de saber si la población de la papita se mantiene en su predio; b) La planta, en este aspecto se preguntó sobre características morfológicas de la planta, así como época de brotación, cosecha y su distribución en el terreno; c) Utilización, o sea el destino, ya sea para autoconsumo o bien para su venta en los mercados locales; d) Interes por sembrarla, este aspecto tiene la finalidad de saber si el productor había realizado algún intento de sembrarla, o bien si conocía alguien que lo hubiera hecho. Las entrevistas se realizaron de - junio a septiembre de 1983 a 1986.

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[1]Artículo presentado en el Simposium de Estrategias de Clasificaciones y Manejo de la Vegetación Silvestre para la producción de alimentos en zonas áridas. (Tucson, Arizona, U.S.A., 12-16 Octubre, 1 987).

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RESULTADOS Y DISCUSION

Durante 1984 se realizaron 124 entrevistas; de las cuales 63 corresponden al estado de Aguascalientes, en la región denominada El Llano; 20 al estado de Jalisco, principalmente en el municipio de Ojuelos; 24 en Zacatecas, especialmente en el municipio de Pinos y 1 4 en Guanajuato. Las entrevistas de estos últimos estados se realizaron durante 1985 y 1986. (Cuadro 1).

Cuadro 1. Entrevistas de papita güera realizadas a productores de maíz y frijol principalmente durante 1984 a 1986.

MUNICIPIO	EDO.	COMUNIDADES	ENTREVISTAS (No.)
Asientos	Ags.	10	10
Aguascalientes	Ags.	28	53
Ojuelos	Jal.	12	15
Villa Hidalgo	Jal.	1	3
Lagos de Moreno	Jal.	1	2
Pânfilo Natera	Zac.	3	5
Pinos	Zac.	9	19
Ocampo	Gto.	2	13
San Felipe	Gto.	1	4
Total		67	124

Se verificó que los productores entrevistados conocieran la papita y la tuvieran en sus cultivos de maíz y frijol de temporal; ya que en la región de Ojuelos, Jal. también se encontraba en el cultivo de trigo. Del 70 al 86% de los entrevistados, manifestaron que en su predio actualmente existe menos papita que antes y que una de las causas, es la utilización de maquinaria en la preparación del suelo para la siembra, ya que estas labores se realizan, en ocasiones, cuando ya ha emergido la planta de papita y al remover la tierra se pierde la planta (Cuadro 2).

Cuadro 2. Existencia de papita güera en el terreno. Entrevistas. 1984-1986.

CONCEPTO	ESTADO AGS.	JAL.	ZAC.	GTO.
	- - - - -	(%)	- - - -	- -
Conoce la papita güera	100	100	100	100
Considera que en su predio hay menos	86	70	70	86
Utilizan maquinaria	70	80	63	100
Afirman que con el uso del tractor se reduce la cantidad de papita	48	35	63	71

Sin embargo, existe otra práctica que favorece la conservación del recurso, ésta es que un 57% en promedio de los entrevistados al realizar las prácticss de cultivo dejan que crezca la planta de papita, ya que no consideran que compita con el cultivo.

En el Cuadro 3, se presentan los datos obtenidos con relación a la planta. Se encontró que existen dos tipos de papita; la que se considera dulce y que es comestible y una amarga o loca (no comestible). Nn el municipio de Pânfilo Natera, Zac. se encontró que los productores tienen perfectamente definidos los predios en que se localiza la papita amarga o loca, lo cual coincide con lo que reporta Quezada y Pimienta (1985).

Las entrevistas expresan, en general, que la papita emerge en junio o bien con "las lluvias" (de un 60 a 100%) y que esta lista para cosecharse a partir de septiembre y octubre, lo cual coincide con lo reportado por Hernández y Bárcenas (1985) quienes señalan que la entrada de papita a los mercados de Aguascalientes inicia a partir de octubre.

Respecto al color de la flor manifestaron que existen los siguientes tipos: blanca, blanca con lila, crema y morada; dominando el color blanco. Otra descripción que hicieron es que existen plantas con hojas glabras y otras pubescentes; también observaron (50%) que en pocas ocasiones las plantas mueren ya sean por enfermedad o por sequía. Aunque son pocos los datos descritos por los productores, éstos identifican la planta en su etapa vegetativa (de producción) como cuando es sólo una varita, o tallo seco, cuando es la época de cosecha. También han observado que la distribución de la planta en la parcela es en pequeñas poblaciones (manchones).

Cuadro 3. Características de la planta. Entrevistas. 1984-1986.

CONCEPTO	ESTADO AGS.	JAL.	ZAC.	GTO.
	- - - - -	(%)	- - - -	- -
Emerge en junio	70	60	74	100
Puede cosecharse a partir de sep-oct.	48	30	11	14
Flor color blanca	65	72	57	100
Distribución en pequeñas poblaciones (manchones)	95	85	93	100

La papita es recolectada para consumo y para venta (Cuadro 4); en Aguascalientes, domina la utilización de la papita para consumo (82% de los casos) a diferencia de los otros estados en que además se vende. El dato anterior coincide con lo reportado por Hernández, S. y Bárcenas, J. (1985) quienes mencionan a Ojuelos, Jal. como el principal origen del producto que se vende en los mercados de Aguascalientes. Sin embargo, la venta de la papita va a estar determinada por la producción natural de cada año, ya que si el año no fue bueno se recolecta sólo para autoconsumo.

Respecto a la cantidad que se recoge, en Aguascalientes reportan de 1 a 15 kg por año tanto de su predio como fuera de él; la recolección la hacen mujeres, niños y hombres, tanto en terrenos de cultivos como en aquellos lugares sin cultivar. Generalmente se remueve la tierra con azadón o bien con maquinaria en el momento del barbecho.

Una práctica que se realiza al recolectar la papa, es dejar la más pequeña para semilla y de esta manera asegurar la nacencia del siguiente ciclo. Esta práctica se realiza principalmente en Aguascalientes y Zacatecas en 47 y 52% respectivamente.

Cuadro 4. Utilización de la papita güera. Entrevistas. 1984-1986.

CONCEPTO	ESTADO AGS.	JAL.	ZAC.	GTO.
	- - - - - -	(%)	- - - - - -	
Consumo	82	35	37	43
Venta y consumo	9	40	44	50
Recolectan de 1 a 15 kg por año	67	20	19	35
Dejan la pequeña para semilla	47	45	52	36

Los productores de esta región han hecho muy pocos intentos por sembrar la papita; ya que un 97%; 80%; 81% y 86% para Ags., Jal., Zac. y Gto. respectivamente, no la han sembrado. Entre las experiencias expuestas al sembrarla, mencionan que es posible obtener buenas producciones y que en aquellos casos que no prosperó, se debió principalmente al tipo de suelo que fue diferente donde se colectó y donde fue sembrado, otro productor expresó que sembró una mezcla de papita dulce con amarga. La siembra generalmente se hicieron en pequeñas superficies (en el lindero de la parcela, 2 ó 3 surcos, etc.).

CONCLUSIONES

Las conclusiones a las que llegó esta investigación exploratoria son las siguientes:

1. Las poblaciones de papita estan disminuyendo.
2. Existen diferentes especies de Solanum que se conocen como papita güera.
3. La papita presenta una distribución en pequeñas poblaciones dentro de la parcela.
4. Es recolectada principalmente para consumo en todas las localidades y para venta en parte de Jal., Zac. y Gto. como actividad secundaria.
5. Son pocos los intentos que los productores han hecho por sembrarla.
6. Es necesario determinar las condiciones edáficas en que se desarrolla la papita.

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Increasing Productivity in the Matorral of Northeastern Mexico: Domestication of Ten Native Multipurpose Tree Species[1]

R. Foroughbakhch, R. Peñaloza, and H. Stienen[2]

Abstract.- Ten multipurpose tree species native to the matorral (low dry shrubland and forest) of the Gulf Coastal plain in north-eastern Mexico were planted in monoculture in four randomized blocks. Measurements of various growth parameters over the first three years were evaluated. Leucaena leucocephala performed best, while the two Prosopis spp and Helietta parvifolia, the only non-legume, did not establish well due to biotic problems which arose under plantation conditions. Three Acacia spp and two Pithecellobium spp (ebano and tenaza) showed high yields which is of great interest since their multipurpose potential is the best of all 10 species. They could be of great importance in rehabilitating badly degraded parts of the matorral before such areas deteriorated to an irreversible desertified condition.

INTRODUCTION AND OBJECTIVES

Linares, in Nuevo León is situated on the coastal plain of the northern Gulf of Mexico (Llanura del Golfo Norte). The region is characterized by a remnant natural vegetation generally referred to as xerophytic shrubland or shrub (matorral xerofito). The regional matorral is composed of a great number of shrub and small tree species and occurs as different structural types and in diverse associations, depending on altitude, soil type, rainfall, frost intensity etc. (Reid et al., 1987: this volume). Approximately 40% of Mexico is covered by similar vegetation (Rzedowski, 1978) so xerophytic matorral has considerable ecological and economical importance.

Over the centuries, the matorral has been subjected to more or less intensitive grazing, timber extraction and clearfelling for other landuses such as horticulture and sown pastures. The remnant matorral has been considerably modified by anthropogenic influence and livestock, giving rise to succesional and disclimax communities. The tendency is for irreversible deterioration and erosion of the soil resource (Gonzalez, 1984). The removal or disturbance of the matorral and the resulting ecological changes in the new agricultural and fruitgrowing areas periodically produce detrimental socio-economic effects (Synnott, 1986).

It is therefore necessary to preserve and enrich the extant matorral vegetation, using native and introduced species with multipurpose characteristics (Foroughbakhch & Peñaloza, 1987), thereby avoiding the enormous investment required to reestablish severly degraded vegetation in dry labile regions, as has been done, for instance, in northern Chile (Stienen, 1985).

In order to obtain basic data on the survival, growth and development of autochthonous matorral tree species under edaphic and climatic conditions typical of the region, a plantation of 10 species had been established near Linares, N.L. The aim of these domestication experiments is to learn more about the behaviour of the species and their management potential, their reaction towards inter- and intraspecific competition away from the natural community, and the importance of biotic and abiotic limitations to their development.

The species were selected for their multipuropose characteristics (Heiseke & Foroughbakhch, 1985; Wolf & Perales, 1985; Foroughbakhch & Martínez, 1986) and productive potential, with a view to their use in managed silvopastoral systems in the

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remnant matorral (Foroughbakhch, Peñaloza & Stienen 1987). This paper reports the establishment of plantations of the 10 native tree species and the results of the first three year's growth.

STUDY AREA AND ECOLOGICAL FACTORS

The experiment is being conducted in the forestry experimental area of the Linares campus of the Universidad Autónoma de Nuevo León (24°47'N and 99°32'W) The plantations are located on a plain 430m a.s.l. about 25 km east of the Sierra Madre Oriental. Originally the area was covered by typical, medium high, semithorny matorral, much of which has now been cleared. The remnant matorral is presently used for silvicultural enrichment treatments, agroforestry and silvopastoral experiments, studies of vegetation dynamic, and ecological observations.

Regional Climate

The study area has a semidry to subhumid climate with very low winter precipitation (system of Köppen, modified by García,SPP, 1981). It is of the (A)C(Wo) type with two periods of summer rainfall, the dry periods occuring in midsummer and winter.

The annual precipitation is 749 mm,of which 594 mm fall between May and October and only 155 mm between Novemeber and April. The mean annual temperature is 22.3°C, but temperatures vary greatly across the year and even within months. Occasional hailstorms and frosts occur, especially at the beginning of the vegetative period in March.

As a consequence of the variable rainfall distribution, the water budget of the vegetation fluctuates markedly. The precipitation/evaporation ratio is 0.48, and the aridity index of De Demertonne is 25.4 (Rojas Mendoza, 1965).

Soil

The soils of the region are derived mostly from the Upper Cretaceous Lutita bedrock. The dominant soils are the deep, dark, loamy-clay, pelic Vertisols which are the result of complex alluvial and coalluvial processes. They are characterized by a high clay content and relatively low organic matter. Their transition stages are Lithosols with a more loamy texture and containing fine sand and gravel.

The regional soils are alkaline due to a high $CaCO_3$ content and have relatively low levels of macro-nutrients,particularly Kjeldahl nitrogen and phosphate (Table 1).

Table 1:

Results of the soil analyses in the plantations with 10 native tree species from the Matorral of NE- Mexico, Linares, N.L. as means of 11 samples from 10 cm depth, in brackets data from 50 cm, 100 cm and 150 cm.

Type of analysis	Result	Annotation
pH (aqu.dest.)	8.5(8.7,8.7,9.0)	alkaline
sand	18 (23,22,24)	Vertisol-like
loam texture %	32 (39,37,42)	soil with high
clay	50 (38,41,34)	content of clay and
organic matter %	2.4(2.4.,1.3,0.9)	low portion of organic matter and
E.C.(umhos/cm)	350 - 700	no salinity
Exchangable Ions		
Mg++	0.25	good
Ca++	10.74	too dominant
K+	0.400.03,0.02,0.05)	weak
Na+	0.20	regular
P disposable(Olsen)	0.20(0.01,0.01,0.01)	deficient
N (Kjeldahl) %	0.11(0.12,0.06,0.04)	very deficient

MATERIAL AND METHODS

Species

All species used in the experiment are native to semiarid zones in Mexico and the adjacent USA, with the exception of Leucaena leucocephala (Lam.) de Wit., which has only recently migrated to the semiarid parts of Nuevo Leon from the more humid zones of the Mexican Gulf Coast. The distribution and uses of each species are shown in Table 2. Seeds were collected in the matorral in the summer and autumn of 1983.

Methods

Production of seedlings was carried out in the traditional way, using plastic bags, 25 x 15 cm, filled with an equal mixture of Vertisol and Litosol. Seeds were hidrated for 24 hr and then planted out,one per bag. Sufficent seedlings of nine species were obtained for the experiment.In the case of Helietta parvifolia (Gray)Bent.,seedling and vegetative material collected in the matorral had to be used because a variety of standard treatments failed to stimulate germination.

Table 2: The tree species and their most important characteristics

	Name	Distribution, remarks	Uses
(1)	Prosopis leavigata (H.B.ex Willd.) M.C. Johnston (Mezquite), Leguminosae	NE-México, especially in mountain Matorral, adventive in Texas. See Prosopis glandulosa.	See Prosopis glandulosa
(2)	Acacia wrigthtii Benth. (Uña de Gato) Leguminosae	Tamaulipas to Baja California, W-Texas to S-California, plain and highland Matorrals. 2-5(9) m, sometimes shrubby, trunk Ø 30 cm. (max.)	Firewood, forage to animals or lopped for fooder.
(3)	Leucaena leucocephala (Lam.) de Wit. (Leucaena, Guaje), Leguminosae	Native from the mexican coastal plains (up to 500 m.)5-8 (20) m. middle hard wood with medium natural resistance, only exceptionally good wood dimensions, sometimes shrybby (in Nuevo León as result of frost).	firewood, charcoal, small constructions, forage with high protein content(mimosine content though restricts its use to forage supplement), windbreaks, living fences, amendment of soils (N-fixing tree), fruits human food (cooked like beans).
(4)	Pithecellobium pallens (Benth.) Standl. (Tenaza), Leguminosae	Nuevo León, Tamaulipas, SL Potosí S-Texas. Plain and highland Matorrals. 2-5 (8) m, wood hard but no good natural resistance, very deep rooting in sandy or gravelly soils particularily on slopes.	Aboveground constructions and simple furnitures made of posts, good forage tree (rumiants).
(5)	Helietta parvifolia (Gray) Benth. (Barreta), Rutaceae	Coahuila, Tamaulipas, Queretaro, Nuevo León, Texas; plain and mountain Matorral. 2-8 m small multitrunk pioneer tree mostly on calcareous (caliche block) soil, very deep rooting in clifts, very durable wood.	Forage tree, posts, fences, constructions, fire wood.
(6)	Acacia rigidula Benth. (Gabia, Chaparro prieto). Leguminosae	Tamaulipas, Nuevo León, SL Potosí Coahuila, S-Texas, Matorral of plain and highlands. 1-6 m, often shrubby, wood of low natural resistence.	Forage tree (esp. goats), small aboveground constructions, firewood.
(7)	Pithecellobium flexicaule (Benth.) Coulter (Ebano), Leguminosae	Tamaulipas, Nuevo León, SW-Texas, lowland Matorral tree, 3-10 (15)m, trunk Ø 50 (120)cm, heavy, hard, dark wood with very good natural resistance, delivers good dimensions.	Timber, any kind of constructions, furniture, fence posts, firewood, charcoal, shade tree for animals and men(arround farms) fruits as human food (coffee substitute)
(8)	Acacia farnesiana (L.) Willd. (Huizache) Leguminosae	All semiard México, S-US, Caribic Islands, Central-and S-America (dry), 1-5(9)m, often shrybby, pioneer invading pastures, wood with some natural resistance, Ø trunk 45 cm (max.).	Good forage tree (small rumiants), firewood, small constructions, sometimes used as fence posts.
(9)	Acacia berlandieri Benth. (Huajillo) Leguminosae	NE and central México, W-Texas Plain and mountain Matorrals, 1-4.5 m, often shrybby, invading pastures, wood with low natural resistance.	Forage tree (especially goats), small aboveground constructions, evtl. firewood.
(10)	Prosopis glandulosa Torr. (Mezquite Leguminosae	NE-Mexican plain and Coahuila, Chihuahua, Sonora, New México, Arizona, S-Texas 5-10 (15)m, trunk 50 (80) cm Ø, good dense dark wood with high natural resistance.	Timber, all kind of construction, fence posts shade tree in pasture grounds and around farms good firewood, charcoal, fruits as human food.

Information partlyfrom: Standley(1926), Heiseke & Foroughbakhch(1985), Wolf & Perales(1985), Foroughbakhch & Martinez(1986), Tellez(1986) and Reid et al. (1987).

The experimental design consists of four randomized blocks, each containing ten plots, 10x10m, without separation between plots and blocks, but with a matorral strip as protection around the whole experiment. Twenty-five plants per plot were planted in a 2x2m spacing in June 1984. The experimental area was cleared one month before by bulldozers. The experiment was evaluated on the basis of measurements of the following parameters: survival, height increment (m), basal diameter (cm), crown proyection area (m^2), and number of stems per plant. These parameters were measured every three months from July 1984 until July 1987. Analyses of variance and regressions were computed using the STATGRAPHICS program. The Duncan test was applied to the last measurements in each year.

RESULTS AND DISCUSSION

The interactions between diverse enviromental factors affect the survival and growth of every species. Thus the existence and development of the diverse plant - component of the matorral needs to be understood as the result of a complex process of adaptation to the ecological conditions of the environment.

In this process, each species adapts to conditions which are fashioned by other components of the system and within time a dynamic balance is established, permitting the survival of all. When this balance is altered by anthropogenic action, each component species in the matorral may subsequently respond differently to biotic and abiotic factors. On one hand, the survival of each species may be enhanced within the matorral community, but each individual is restricted to a determined rate of individual growth and development.

The results gained from cultivating 10 tree species characteristic of the matorral in plantation over three growing seasons, reveal their natural aptitude to thrive in the area as well as their dependence on the diverse plant community.

Survivorship

Species survivorship over the first three years is presented in Fig.1. Only four species show some degree of mortality. Different reasons are involved in each case.

Leucaena leucocephala suffered from frosts in the year the plantation was established. This affected both the growth and survival of the species. The 10% loss of plants is not high and the persistence of the survivors without further loss demonstrates its adaptability to the edaphic and climatic conditions. The mortality may have been accentuated by the young age of the plants and the lack of physical protection of the matorral.

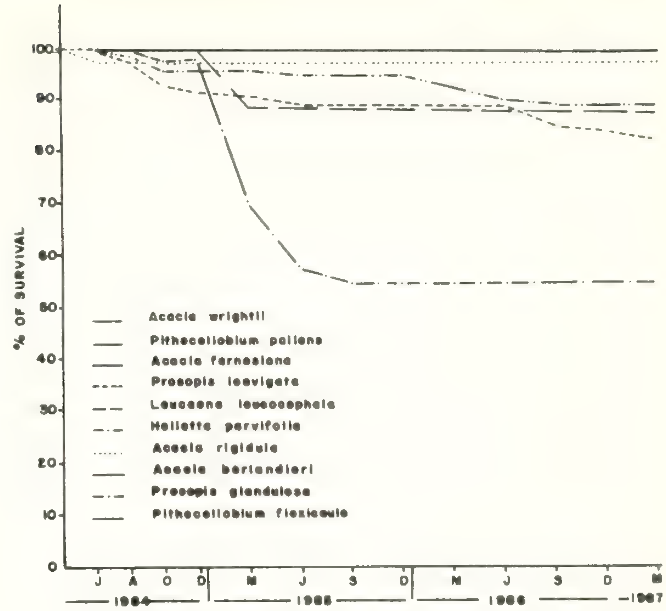

FIG. I PERCENTAGE OF SURVIVAL OF THE SPECIES IN LINARES N.L., MEXICO

Both Prosopis spp show the effect of biotic factors which manifest themselves when species are grown away from the protective proximity of the other matorral components. Both Prosopis laevigata and P.glandulosa were intensively attacked by grasshoppers (Melanoplus sp.) in plantation, resulting in their complete defoliation from the time of establishment of the plantations. Insect grazing in successive growing seasons combined with browsing by Jack rabbits (Lepus californicus) have resulted in a permanent reduction in the number of mezquite plant.

Helietta parvifolia has shown the highest mortality, for which the most probable explanation is the origin of the plants. As the seeds would not germinate, even after various treatments (mechanical and chemical scarification, gibberelic acid, hot water etc.), it was necessary to look for seedlings and root sprouts in the matorral near the plantations. It was difficult to maintain sufficient transplanted material alive in plastic bags for two months prior to planting out, probably because the roots were damaged during transplanting. In addition frosts contributed to the mortality of the debilitated plants and did not permit satisfactory development. About 45% of plants were lost, but those surviving this critical period suffered no further mortality.

Acacia and related Pithecellobium were the most adaptable species tested, with 100% survival. The capacity for ready establishment confers to these species, especially the acacias, their aggresive pioneer characteristics in the invation of pastures, fallow

land and disturbed natural vegetation.

Height Increment

The increses in height of a plant species is normally a good index of its capacity for successful development, especially in the initial establishment phase. When other factors such as spacing,competition, soil quality and climate later begin to take effect, the absolute importance of height increment diminishes and it needs to be evaluated with other criteria for monotoring growth. In the present experiment, the 10 species show surprisingly variable height increments in the first three years (Fig. 2 and 3).

Leucaena leucocephala, the only species not native to the matorral but in the process of invading at the sides of roads, fields and the edges of the natural vegetation, showed a prodigious growth potential from the moment of plantation, but also suffered height reductions in winter with the onset of the frosts. Its sensitivity to low temperatures limits its use as a forest tree. However, its rapid growth makes it ideal for silvopastoral and agroforestry purposes. Acacia farnesiana, A. wrightii and Pithecellobium pallens show good growth potential, although less than that of Leucaena leucocephala, and do not suffer reductions in height due to environmental causes.

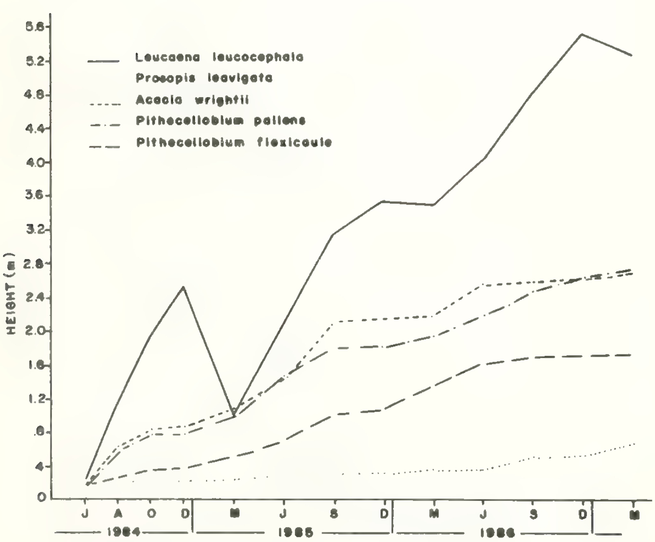

FIG. 2 GRAPHS OF HEIGHT INCREMENT FOR TEN SPECIES FROM THE MATORRAL (first group)

Acacia berlandieri, A. rigidula and Pithecellobium flexicaule have similar height increments than the aforementioned group. These species have not shown any effects of abiotic stresses.

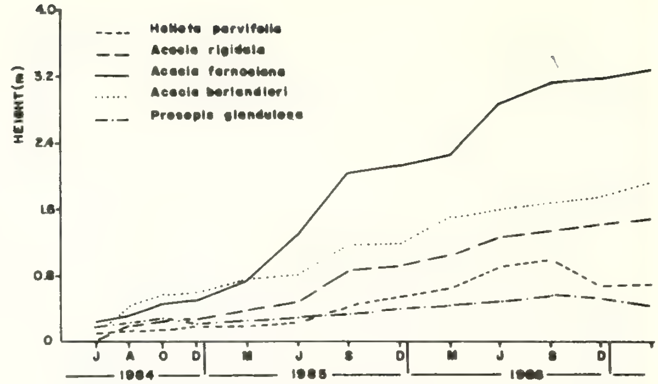

FIG.3 GRAPHS OF HEIGHT INCREMENT FOR TEN SPECIES FROM THE MATORRAL (second group)

Prosopis laevigata, P. glandulosa, and Helietta parvifolia constitute a special group of species. Their growth potential cannot be deduced from this experiment because of repeated grazing or establishment problems (cf.Section 4.1). When the mezquite plants were covered with a net protecting them from insects and rabbits, their growth improved although the height increments were still less than the other species. Methods for the establishment of mesquite have to be found because the species are of great importance for their multipurpose characteristics on both sides of the border (Felker 1979; NAS, 1979).

Analysis of variance showed that differences in height increment between all species were very significant. The significant difference between blocks suggests that soil conditions across the experimental area are not homogeneous, reflecting the actual situation in the matorral.

Fig. 4 permits the species to be grouped into three strata on the basis of mean height. The species groups are important for silvicultural management because species with similar growht rates are likely to be compatible in mixed plantations whereas a faster growing species is likely to dominate when species with unequal growth rates are grown together.

Diameter Increment

The increase in basal diameter of the species shows a similar pattern to that for height increment. Thus Leucaena leucocephala shows the larges increment in basal diameter after three years (Fig.5). The basal diameter of Acacia wrightii increases constantly across each growing season so it ought to rapidly develop its photosynthetic surface (crown). Acacia farnesiana shows a similar pattern, as does Pithecellobium pallens to a lesser degree.

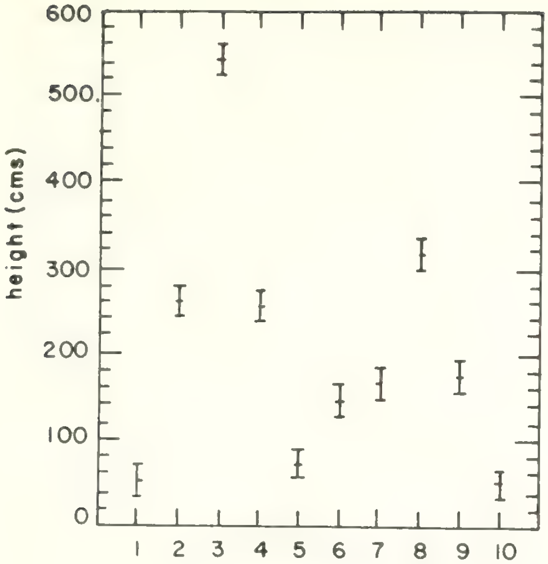

FIG. 4 Height growths of the 10 species from the trials at Linares N.L. after three years of plantation

The remaining species have smaller diameter increments in accord with their increases in height. <u>Helietta parvifolia</u> showed a negative increment in basal diameter in the third year due to the death of thick-stemmed plants after the second growing season.

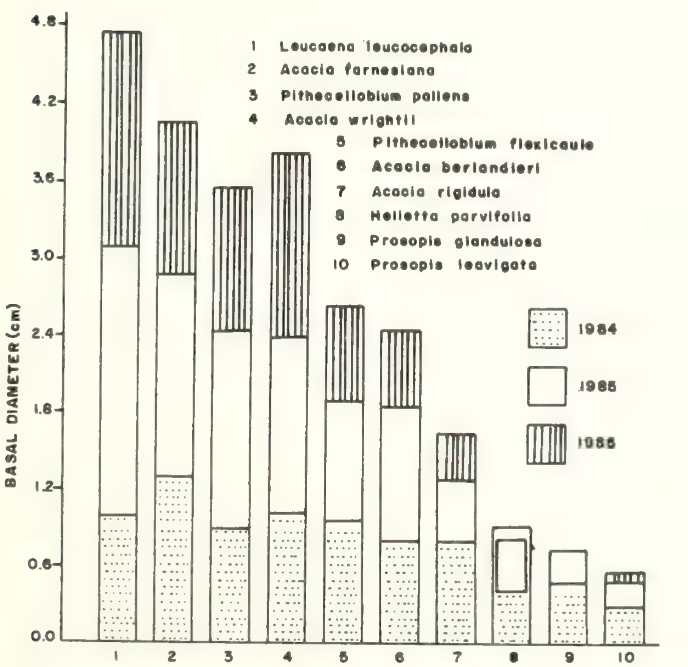

FIG 5 INCREMENT OF THE BASAL DIAMETER FOR THREE VEGETATION PERIODS

Table 3 shows the analysis of variance of basal diameter, and the mean diameter and 95% confidence limits for each species after three years of growth. Blocks show the same heterogeneity as with height increment (cf. Section 4.2). The mean basal diameters are presented in Fig. 6. <u>Acacia wrightii</u> and <u>A. farnesiana</u> have smaller diameters than <u>Leucaena leucocephala</u>. However, these three species together with <u>Pithecellobium pallens</u> have the best basal wood formation. The rapid increase in diameter of the two acacias does not correspond with their vertical growth, and suggests that their pioneering characteristics are due to their capacitv for accelerated crown development.

Under normal conditions, wood production (and hence stem diameter) is a function crown size (projected foliage cover) in arborescent dicotyledons in which the lateral branches grow more quickly than the central apex. This growth habit gives rise to a broad dispersed canopy, especially in poor or dry sites (Daniel, Helms and Baker, 1979). As these acacias have a large photosynthetic surface (see below), their basal diameter increment is high.

Table 3: Analysis of variance for the basal diameter of 10 species in four blocks at the end of the third year (1986) with table of means.

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	644.64911	12	53.720759	38.335	.0000
RFDOM3.especie	609.97789	9	67.775321	48.364	.0000
RFDOM3.bloque	34.67122	3	11.557074	8.247	.0000
RESIDUAL	486.26989	347	1.4013541		
TOTAL (CORR.)	1130.9190	359			

Table of means

Level	Count	Average	Stnd. Error (internal)	Stnd. Error (pooled s)	95 Percent Confidence for mean	
especie						
1	36	1.1055556	.1879271	.1972980	.7174193	1.4936918
2	36	3.8861111	.2107113	.1972980	3.4979749	4.2742474
3	36	4.6861111	.2101078	.1972980	4.2979749	5.0742474
4	36	3.5527778	.1696161	.1972980	3.1646415	3.9409140
5	36	1.1555556	.3038234	.1972980	.7674193	1.5436918
6	36	1.7500000	.1435104	.1972980	1.3618637	2.1381363
7	36	2.7166667	.1543291	.1972980	2.3285304	3.1048029
8	36	4.0222222	.2208609	.1972980	3.6340860	4.4103585
9	36	2.1722222	.1718532	.1972980	1.7840860	2.5603585
10	36	.9361111	.2139631	.1972980	.5479749	1.3242474
bloque						
1	90	2.5888889	.1811011	.1247822	2.3434100	2.8343678
2	90	2.4111111	.1999591	.1247822	2.1656322	2.6565900
3	90	3.1033333	.1862562	.1247822	2.8578544	3.3488122
4	90	2.2900000	.1777235	.1247822	2.0445211	2.5354789
Total	360	2.5983333	.0623911	.0623911	2.4755939	2.7210728

Crown Development

Table 4 presents the analysis of variance for projected crown cover as determinated from the vertical projection of two perpendicular crown diameters (Müller-Dombois and Ellenberg, 1974).

Crown growth is significantly different between species and corroborates the discussion in Section : the acacias, especially <u>Acacia wrightii</u>, quickly produce a broad crown, explaning their ability to produce a

large basal diameter. The data suggest that the acacias are better able to establish in cleared sites within their natural distribution than other components of the matorral.

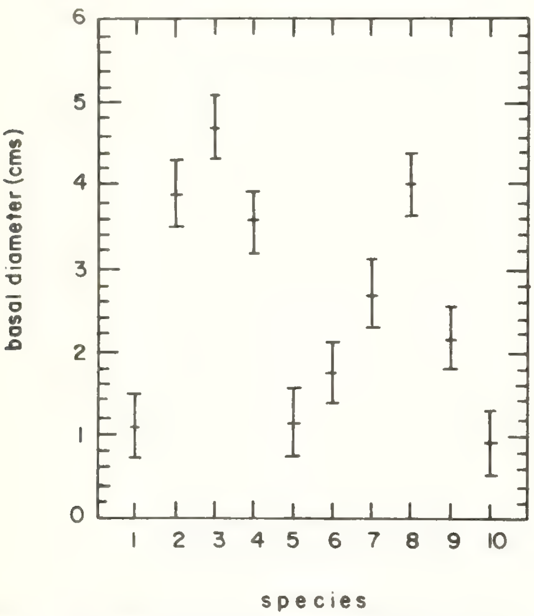

FIG 6- Distribution of the basal diameter(cm) of the 10 species after three years of plantation at Linares

Table 4: Analysis of variance for the crown diameter of 10 species in four blocks at the end of the third year (1986) with table of means.

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	729.06855	12	60.755713	53.454	.0000
RFDOM3.especie	722.25622	9	80.250691	70.606	.0000
RFDOM3.bloque	6.81233	3	2.270778	1.998	.1140
RESIDUAL	394.40041	347	1.1366006		
TOTAL (CORR.)	1123.4690	359			

Table of means

Level	Count	Average	Stnd. Error (internal)	Stnd. Error (pooled s)	95 Percent Confidence for mean	
especie						
1	36	.1913889	.0500256	.1776858	-.1581650	.5409428
2	36	3.9113889	.1741310	.1776858	3.5618350	4.2609428
3	36	4.3633333	.3825126	.1776858	4.0137794	4.7128873
4	36	2.8508333	.1509417	.1776858	2.5012794	3.2003873
5	36	.2486111	.0489544	.1776858	-.1009428	.5981650
6	36	2.1177778	.1587861	.1776858	1.7682238	2.4673317
7	36	1.9630556	.1454030	.1776858	1.6135016	2.3126095
8	36	3.1025000	.1651677	.1776858	2.7529461	3.4520539
9	36	2.0411111	.1727769	.1776858	1.6915572	2.3906650
10	36	.3680556	.1030317	.1776858	.0185016	.7176095
bloque						
1	90	2.1266667	.1880352	.1123784	1.9055893	2.3477440
2	90	1.8890000	.1675879	.1123784	1.6679227	2.1100773
3	90	2.2440000	.1731229	.1123784	2.0229227	2.4650773
4	90	2.2035556	.2144605	.1123784	1.9824782	2.4246329
Total	360	2.1158056	.0561892	.0561892	2.0052669	2.2263442

Fig. 7 Shows the projected foliage cover of each species after three years and highlights the high growth potential of Leucaena leucocephala in comparison with the nine species native to the matorral. The Pithecellobium spp demonstrate a surprising capacity for early crown expansion similar to the acacias. This is an important consideration for silvicultural management in the matorral. Aggressive crown expansion may inhibit the growth of slow growing, valuable wood producing trees in mixed stands if species have heterogeneous growth rates.

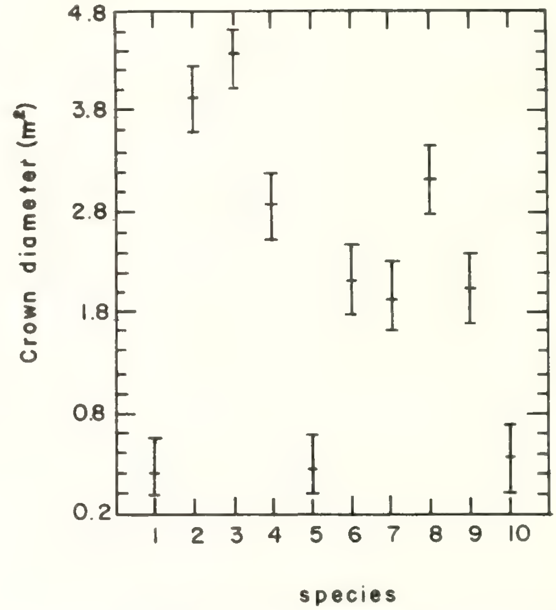

FIG 7 Crown development (m^2) of the 10 species after three years of plantation at Linares N.L.

The Prosopis spp. and Helietta parvifolia show little canopy growth due to the limitations mentioned above.

The analyses of the development and environmental responses of each tree species using commonly accepted criteria such as survivorship and growth in height, diameter and projected foliage cover, suggest that each species has unique aspects of growth potential. Analysis of the relationships between variables helps to highlight these characteristics. Table 5 presents the correlations between crown and basal diameter after three years. In Table 5 two points are important:

Table 5: Correlation coefficients (a) between heigh and basal diameter after two and three years of the experiment and between crown diameter and basal diameter after three years (b)

Species	1985a	1986a	1986b
Prosopis laevigata	0.73	0.48	0.15
Acacia wrightii	0.67	0.29	0.53
Leucaena leucocepahala	0.86	0.83	0.38
Pithecellobium pallens	0.78	0.48	0.34
Helietta parvifolia	0.52	0.77	0.07
Acacia rigidula	0.64	0.61	0.62
Pithecellobium flexicaule	0.56	0.43	0.31
Acacia farnesiana	0.75	0.53	0.59
Acacia berlandieri	0.83	0.48	0.51
Prosopis glandulosa	0.83	0.84	0.30

a) Leucaena leucocephala shows a high correlation between heigh and basal diameter for both growth periods, confirming its great potential for growth and biomass production observed both in the field and elsewhere (CATIE, 1986). However, the correlation between projected crown cover and basal diameter is low. The crown is not small but vertically long and slender, presenting a different type of crown than most of the tree species in the matorral.

b) The high correlation between height and basal diameter for the Acacia spp in the second year disappears completely in the following year. This is the result of their sudden growth in basal diameter, correlated with rapid crown expansion.

These correlations corroborate the conclusions of earlier sections but need to be confirmed after a longer observation period of the least one third of a regular rotation.

The growth of the ten species in plantation is very different from the growth rates of matorral species in the natural community. Heiseke and Foroughbakhch (1985) obtained a mean annual diameter increment (at breast height) of 0.2-0.4 cm/year and a height increment of 13-24 cm/year for woody species in matorral close to the plantations. The data are the means for approximately 30 species, including most of those grown in plantation. Although not directly comparable with the growth rates reported in this paper, the data suggest very slow growth rates for species growing under conditions of interspecific competition in the natural community and emphasize the high yield of many native matorral species in managed plantations.

The high biomass production of most of the species in plantation is not only relevant to the production of browse for cattle (Tellez, 1986, Reid et al., 1987) but also for timber (posts) and fuelwood production. In Table 6, the usable wood volume of three species is estimated after three years growth. These data indicate a much higher wood production in plantation than in the natural community (cf.Heiseke and Foroughbakhch, 1985).

Table 6: Volume (V) production in m^3 of utilizable wood for three species from the Matorral in plantations near Linares, N.L.

Species	No stems/ha	V/ha
Leucaena leucocephala	7150	16.2
Pithecellobium pallens	5550	3.8
Acacia farnesiana	9025	11.5

after $V= \pi (BD+BRD/4)^2 X H$ (BD) at 10 cm
H = 120 cm (BRD) at 130 cm

CONCLUSIONS

More than three years experience in growing 10 native species in plantation in the Linares region, Nuevo León, shows the following:

a) As expected, all species are well suited to the edaphic and climatic conditions of the region, but establishment in an unprotected, cleared site was variable due to biotic factors such as insect grazing, and qualitiy and type of the propagative material.

b) Leucaena leucocephala shows the highest yields and constitutes an important multipurpose tree species for the region.

c) The Acacia spp show characteristics of woody pioneer species and a strong capacity for precocious canopy expansion. Pithecellobium pallens and to a lesser degree, P. flexicaule, behave similarly. The latter two species are exploited for multiple purpose in the matorral and should be considered for future planting.

d) The establishment problems, vegetative and sexual reproductive potential, and allelopathic character of Helietta parvifolia require detailed study because the species is an important timber resource in the matorral, providing the rural community with hard, durable posts for fences and construction.

e) The two Prosopis spp. showed limited growth in plantation because they were attacked by insects and lagomorphs. This situation needs to be born in mind in future plans for the silvicultural management of the matorral.

f) All species not affected by biotic stresses showed good growth in plantation and a high potential for incorporation in plans for the diversified silvicultural management of matorral areas.

SUMMARY

Then native tree species with multipurpose characteristics from the Matorral (low dry forest)region of the Coastal Plain of NE-Mexico were planted in monoculture in randomized plots in four blocks. For three years continual measuring of different growth parameters was conducted and the resulting data were evaluated.

Leucaena leucocepahala performed best, while the two Prosopis sp. and Helietta parvifolia, the only non Leguminosae, could not be established well due to biotic problems which arose under plantation conditions. Very well developed the three less desired Acacia sp., and the two Pithecellobium sp., Ebano and Tenaza still showed

good results which is of great interest since their integrated multipurpose aptitudes are the best of all tested species. They could be of great importance to rehabilitate badly degraded Matorral before it enter to an irreversible stage of destruction.

ACKNOWLEDGEMENT

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MANEJO Y COMERCIALIZACION DE LA LECHUGILLA EN ZONAS ARIDAS DE TAMAULIPAS[1]

Luis Hernández Sandoval y Jorge Jiménez Pérez[2]

Resumen.--La lechuguilla es un recurso sobreexplotado en Tamaulipas, por lo que se plantea un manejo de acuerdo al conocimiento tradicional y a la tecnología moderna para mejorar la calidad de la fibra, así como comercializar los productos transformados del ixtle y con esto aumentar los ingresos de los campesinos.

INTRODUCCION

En Tamaulipas, la zona árida se encuentra en la porción suroeste, formando parte de la provincia biótica del Desierto Chihuahuense. A pesar de las condiciones ecológicas tan extremas, estas zonas presentan una riqueza florística con grandes posibilidades de aprovechamiento. En México existe una gran tradición en el uso de fibras duras o ixtles para jarciería, cestería y cordelería, destacando en el norte la lechuguilla (Agave lechuguilla Torr.) por su calidad, utilidad y abundancia.

En la región ixtlera, y en particular para Tamaulipas, la explotación de este recurso se ha llevado en forma silvestre al parecer desde la época prehispánica. Sin embargo, su aprovechamiento no ha tenido una planeación adecuada y en algunos lugares se ha sobreexplotado, llegando a graves daños de erosión genética, mientras que en otros, la recolección y talla del ixtle se ha abandonado, sustituyéndola por actividades económicas más remunerativas o por la migración a diversas ciudades o al extranjero. Esto ha causado problemas tanto ecológicos como socioeconómicos, por lo que la Universidad Autónoma de Tamualipas y la Agencia Internacional para el Desarrollo han planteado un proyecto sobre manejo y comercialización de lechuguilla en un área pequeña, donde, si se obtienen resutados positivos, se desarrollará un programa regional.

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[1]Este trabajo fue presentado en la reunión Estrategias de clasificación y manejo de vegetación silvestre para la producción de alimentos en zonas áridas. 12 - 16 de octubre de 1987.

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ANTECEDENTES

Descripción.

La lechuguilla es una planta en forma de roseta de color verde amarillento, de 25 a 30 cm de alto; con el sistema radicular superficial y una corta raíz principal; hojas falcadas o curveadas de 30 a 35 cm de largo y de 2 a 3 cm de ancho; los márgenes son desprendibles y tienen de 8 a 12 dientes doblados hacia abajo. La inflorescencia (quiote) es una panícula de 2 a 3 m de alto, con las flores agrupadas de 1 a 3 en la parte superior, de 2 a 4 cm de largo con pétalos lineares amarillos y frecuentemente manchados con rojo o purpura; cápsulas oblongas a piriformes de 18 a 25 por 11 a 18 mm ; semillas de 4.5 a 6 por 3.5 a 4.5 mm. (Gentry 1982, Nieto-Pola 1983).

Reproducción

La reproducción de la lechuguilla es casi enteramente asexual, observándose en la producción rizomatosa de brotes o "hijuelos". Este fenómeno tiene estrecha relación con el tipo de manejo que se le dá a la planta, evitando la producción de flores y frutos.

Con respecto a la reproducción sexual, Freeman y Reid (1985), citan que la lechuguilla florece en la mayoría de los años entre mayo y junio, y retardándose en los periodos de invierno o épocas de lluvia muy secos. La floración está relacionada con el número de hojas por roseta, es decir que se presenta en los aquellos individuos con un rango entre 42 y 69 hojas, asumiendo que esto corresponde a una edad aproximada de 20 años a la fecha de floración. Por otro lado, existe una alta producción de semillas viables por planta, encontrando que no tienen requerimientos para romper la latencia y germinando rápidamente cuando hay humedad suficiente.

Ecología

La lechuguilla es uno de las especies más representativas del Desierto Chihuahuense. Marroquín (1964), menciona que la lechuguilla se encuentra en los matorrales micrófilos o de "gobernadora" y principalmente en los rosetófilos, asociada con especies de los génros *Larrea*, *Dasylirion*, *Acacia*, *Flourencia* etc., sobre las sierras consuelos de origen calizo, llegando a ocupar las partes planas, siempre y cuando presenten buenas condiciones de drenaje, es decir, en suelos pedregosos. Llega a soportar temperaturas extremas, características de los climas áridos y semiáridos, con precipitaciones pluviales de 200 a 500 mm. Sus límites altitudinales son de 950 a 2350 msnm. (Nieto-Rola, op. cit.)

Evolución y Taxonomía

Dentro de la familia Agavaceae, el genero *Agave* tiene estrechas relaciones con los generos tropicales de Centro y Sudamerica, sin embargo, al parecer su origen y diversificación se da en el centro y norte de México, como componente de la flora Madroterciaria (Gomez-Pompa 1965).
La lechuguilla pertenece al grupo Marginatae del subgenero Littaea; Gentry (op. cit.) observa que dentro del grupo Marginatae, que se distribuye desde el sur de México hasta el norte de la Sierra Madre Oriental, existe un complejo de especies relacionadas con la lechuguilla. Este está formado por *A. lophantha* Schiede, *A. funkiana* Koch & Bouché, *A. xylonacantha* Salm., y *A. lechuguilla* Torr. en el cual se dan procesos de flujo genético e hibridización. Por otro lado, se han reportado estrechas relaciones entre la lechuguilla y otras especies afines, observando estos procesos y fenomenos en la zona de estudio.

OBJETIVOS Y METAS

Los objetivos contemplados son: manejar el recurso con fines de conservación y mejoras en la calidad de sus fibras o "ixtle" para aumentar los ingresos de los campesinos. Las metas a corto plazo son: a) realizar una exploración etnobotánica; b) definir el area de estudio; c) formar una unidad de propagación; d) desarrollar técnicas de manejo y selección de materiales; e) capacitar a los campesinos; f) realizar estudios de mercado y comercializacion.
A mediano y largo plazo se plantea la obtención y selección de materiales para la formación de un banco de germoplasma con fines de fitomejoramiento; realizar actividades de reforestación; formación de agroindustrias para la transformación de productos de ixtle; comercialización del producto y extensión de las actividades a nivel regional.

AVANCES Y RESULTADOS

En Tamaulipas la explotación de lechuguilla se realiza en los municipios de Jaumave, Miquihuana, Tula, Bustamante, Palmillas, Burgos, San Nicolás, San Carlos y Cruillas, sin embargo, en los tres primeros se da la mayor producción.
El área de estudio seleccionada fue el ejido la Reforma, en el municipio de Jaumave, el cual se encuentra a 40 km al SW de Cd. Victoria y a una altitud de 900 m.s.n.m., formando parte de la cuenca del río Chihue y con vegetación de matorral alto subinerme, matorrales rosetófilos y espinosos sobre suelos de origen calizo.

Exploración etnobotánica

Se tienen registros arqueológicos (Callen, 1965) del uso de las fibras por el hombre desde 7000 años A.de C. Este autor señala que se debe haber descubierto el uso de las fibras al momento que empezó a utilizar los agaves como alimento. González y Scheffey (1964) mencionan que es conocido el uso del ixtle en la época precolonial por los escasos pobladores del norte de México. Igualmente, se tienen registros de uso en las ciudades mesoamericanas, además de contar con el nombre nahuatl para la lechuguilla "metometl" y la palabra "ixtle" para designar la fibra (Gentry, op. cit.).
Dentro de la exploración etnobotánica de este proyecto se registraron los nombres de los tipos de lechuguilla que reconocen los "tallanderos" o "ixtleros", como se designan en esta zona a los que tallan lechuguilla. Estos nombres coinciden en su mayoría con los que describe el Ing. Montemayor a principios de siglo (Gómez Garza, 1908). En nuestros datos de campo obtuvimos la siguiente información de los tallanderos: reconocen la lechuguilla "ceniza" (que corresponde seguramente a la verde azulosa de Montemayor), la "verde", la "amarilla", la "prieta" y la "gato" (es decir con vetas amarillo y verde). Sin embargo, los términos "reventona" o "mala" se asocian a cualquiera de los nombres anteriores si consideran que la fibra es de mala calidad, comprobandolo al doblar una hoja y observar el tipo de fisura en la epidermis, ya que si se marca en forma de cruz, no la consideran "buena". Mencionan además que la de Jaumave es más blanca que

la del resto del estado. Por otro lado utilizan para obtener fibras más suaves al "mesotillo" (*A. lophantha*) y la "jarcia" (*A. funkiana*), que según algunos autores produce el "ixtle de Jaumave". Al parecer, la hibridación que existe entre las dos especies anteriores y *A. lechuguilla* forman el complejo de especies sitado por Gentry (op. cit) y dan como resultado esta gran variedad de nombres y tipos de fibras.
La forma de colectar la lechuguilla en esta zona es, desprender el cogollo con una garrocha de madera y una argolla metálica en un extremo, depositándolos en un cesto llamado "oaxaca". Este cesto es construido con madera de una especie no identificada que ellos llaman "membrillo" que se tuesta y dobla formando los arcos, para después tejerla con cordel de ixtle. Cuando se reune la cantidad de cogollos suficientes para la jornada, se procede a tallarla. Para esto utilizan como base un trozo de madera de aproximadamente 35 cm de largo por 10 de ancho y 4 de espesor de "soyate" (*Nolina nelsonii*), llamado "banco", raspandose con un instrumento de metal de filo romo o "tallador" con un mango de "barreta china" (*Fraxinus greggii*) y un gancho en el extremo para fijarlo a un poste, permitiendo el movimiento sobre su eje, despues, atora con su mano izquierda un manojo de hojas de lechuguilla con ayuda de un trozo de madera denominado "bolillo" y, presionando las hojas contra el banco con el tallador, obtiene la fibra. Despues la tiende al sol para su secado y la acumula para su venta (figura 1).

Figura 1. Lechuguilla seca para venta

Marroquin (op. cit.) señala dos métodos diferentes de tallado para Coahuila, uno que es cortando la planta, tallando la parte externa de la roseta, y el otro, con la planta en pie, jalando la fibra con unas tenazas.
La utilizacion de la fibra a nivel local es para la fabricacion de cordelería, escobetas, cepillos, peines y varios artículos tejidos. Otros usos muy extendidos son el de la raíz o "amole" como jabón; las flores son comestibles y las preparan de diferentes maneras; el escapo o "quiote" se utiliza como soporte para techar casas y cuando tiernos, los niños los consumen como caña de azucar; de la roseta deshojada o "piña" obtienen el "mezcal de lechuguilla".

Manejo

El manejo tradicional que le dan los campesinos a la lechuguilla se realiza, como se mencionó anteriormente, por medio de la corta de los cogollos de aquellos individuos considerados como poseedores de fibra de buena calidad. Cuando esta acción se realiza por primera vez se le denomina "capar" la lechuguilla. La frecuencia de recolección por individuo, varía según la zona, de seis meses a dos años, considerando este último periodo como el más adecuado. En los casos en que se requiera la explotación de manchones de lechuguilla de mala calidad, se dice que si se "capa", a los dos años comenzará a producir mejor ixtle.
Los datos de producción y rendimientos para Tamaulipas están dispersos y varían según los autores, por lo que se presentan datos de producción en los años de 1970 y 1975 en la tabla 1 (Menchaca 1978).

Tabla 1. Producción de ixtle y su valor en Tamaulipas. (En miles).

	1970		1975	
Municipio	cant. Kg	valor $	cant. Kg	valor $
Jaumave	700	2 660	600	4 200
Miquihuana	250	950	200	1 400
Tula	300	1 140	600	4 200
Total	1 250	4 750	1 400	9 800

Observando que la produccion ha aumentado levemente, quizá debido mas a problemas socioeconomicos que al tipo de manejo.
Con el fin de aumentar la produccion, se han utilizado maquinas desfibradoras desde principios de siglo, pero la mecanizacion de la lechuguilla no ha prosperado por las siguientes causas: 1) bajo contenido y poca uniformidad de fibra en las hojas, que hace incosteable el transporte de la materia prima; 2) la poca uniformidad de los cogollos; 3) se acelera el agotamiento del recurso; 4) disminuye la mano de obra, aumentando el desempleo. Sin embargo, a medida que se vayan resolviendo estos problemas, la mecanización será posible y aceptada por los campesinos de la region, aumentando la produccion de fibra.
Con respecto a los rendimientos por unidad de área, encontramos datos poco uniformes, así, Martínez (1936) registra un máximo de 30 000 plantas/Ha, Valero (1949) reporta 11 000 plantas/Ha y, finalmente Zapien (1980), encuentra 13 200/Ha. Esta información en Tamaulipas se esta captando por el personal del Instituto de Investigaciones Alimentarias (IIA) y los técnicos de la SARH, delegacion Tamaulipas.
Para el manejo de la lechuguilla en la zona de trabajo, se construyó un vivero de media hectárea para los ensayos de propagación y fitomejoramiento, el cual está cercado con especies vegetales útiles a la comunidad, tales como pitayos (*Stenocereus griseus*) y garambullos (*Myrtillocactus geometrizans*). Se implementó una unidad de propagacion y producción de planta por semilla, iniciando a la fecha colecciones para banco de germoplasma y poder realizar pruebas comparativas de germinacion; y otra unidad en areas abiertas, para pruebas de reforestacion en zonas susceptibles de erosion y desmontadas. El material utilizado ha sido el recomendado por los campesinos, siguiendo su origen a partir de individuos con fibras de alta calidad. En ésta se sembraron 500 plántulas con tamaños entre 10 y 20 cm. y de 5 a 8 hojas, marcando sus lineas parentales, su lugar de procedencia y tipo de lechuguilla trabajando al momento con la "ceniza", "prieta", "gato" y la "amarilla". A partir de esto se ha iniciado un muestreo de crecimiento por mes (figura 2).
Para estas actividades se está capacitando a dos campesinos, encargados a la vez del vivero.

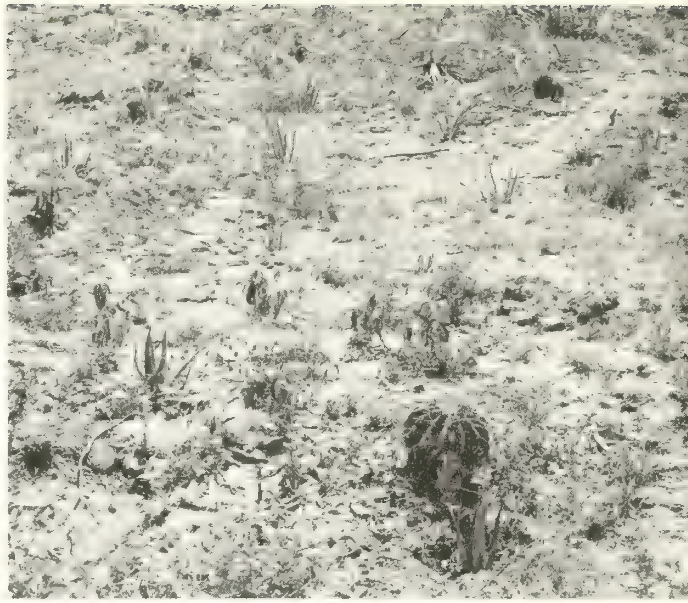

Figura 1. Lechuguilla sembrada en el área de experimentacion.

Comercializacion

El registro mas antiguo que se tiene, ya como explotación de la lechuguilla, data del año de 1741 (Marroquin op. cit.), realizándose por pequeños propietarios y campesinos al servicio de hacendados, durante la colonia y principios del México Independiente; como producto secundario se trabajó hasta principios de este siglo en que tuvo alta demanda. De esas fechas a la actualidad ha existido una enorme fluctuación en precios y demanda, principalmente por las guerras y la competencia con las fibras sintéticas. Con el propósito de organizar la producción y comercialización de la lechuguilla, en 1932, los Generales Saturnino Cedillo y Francisco Carrera Torres fundaron en Tamaulipas la Nacional Ixtlera (Martinez, 1972). Hacia 1940 El Gral. Lazaro Cárdenas decreta la creación de la Forestal F.C.L. (Federación de Cooperativas Limitadas), liquidando a las organizaciones anteriores. Los objetivos de esta empresa paraestatal son: el comprar toda la lechugilla tallada por los campesinos, pagándoles un anticipo, para después del balance anual, remunerar los sobrantes de la comercialización. Sin embargo, los datos socioeconómicos que se presentan a continuación nos muestran una realidad muy difícil de cambiar:
Del total de la población de la zona ixtlera del país según Caire (1985), en 41 municipios, encontró que del 51% de hombres, el 22% eran económicamente activos, y del 49% de mujeres, el 3.89% ;
un tallandero puede producir un promedio de

4 a 5 kilos diarios de fibra seca, que se vende a 450 pesos por kilo en la actualidad, por lo que obtiene, en el mejor de los casos, 2250 pesos, cuando el salario mínimo es de 6150.

Con respecto a la comercialización de la fibra, se está promoviendo una campaña de producción de artesanías de ixtle, tales como oaxacas, cunas, portamacetas, bolsas, adornos, etc. en coordinación con el programa de crédito a la mujer campesina del Banco Rural, Fonart y la Unión de Artesanos de la Cd. de Tula, Tamps., para la evaluación de costos, capacitación y distribución de los productos en los mercados regionales y nacionales.

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Revised Universal Soil Loss Equation for Western Rangelands[1]

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Abstract.--The Universal Soil Loss Equation has been revised to accommodate field conditions found throughout the western United States. The revision uses a subfactor approach to evaluate the "C" factor and additional algorithms to describe the "LS" and "P" factors. The revised "C" factor is now the product of subfactors: PLU (prior land use), CC (vegetation canopy cover), SC (surface ground cover), and SR (surface roughness). Included in these subfactors are conditions for vegetation canopy height and root biomass. Algorithms for "LS" consider non-linear interactions between slope steepness and length. The algorithms for "P" are based on surface roughness, slope steepness, and runoff reduction.

A procedure is presented for estimating, from above ground biomass, the root biomass in the upper 100 mm of the soil profile of various rangeland vegetation types. A sensitivity analysis of the root biomass input to the subfactors PLU and SR is presented to illustrate the importance of root biomass to erosion from rangelands.

Rangeland soil loss estimates are made from a wide range of assumed factor values using the old and revised USLE. Also, each equation is used to estimate soil loss and the results are compared to actual soil loss measurements from simulated rainfall plots.

INTRODUCTION

Surface soils of much of the western rangeland areas of the U.S. have been badly eroded. From the viewpoint of a soil morphologist, such soils are only partly weathered parent geologic material. Climatic and agronomic conditions which might lead to soil formation like that encountered in cultivated agricultural areas are unfavorable or at best, soil building occurs at a reduced rate. When unprotected, the most fertile A-horizon is rapidly removed by erosion under the sparse vegetation found on such deteriorated areas. Thus, preservation of rangeland soil resources is a high priority need to the conservationist/environmentalist and, from the viewpoint of the rancher trying to maximize forage production, soil protection is critical if plants are to have a sufficient nutrient and soil moisture reservoir for growth.

The severity of rangeland erosion problems has been illustrated with published work from Langbein and Schumm (1958) and Marshall (1973). Figure 1 illustrates in a conceptual way the water and wind erosion problem as a function of annual precipitation.

Sediment yield and erosion are closely related phenomenon although yield reflects the transport efficiency of not only the upland erosion processes but also that occurring in the channels of a watershed. Sediment yield also includes deposition of eroded materials in natural and man-made features such as terraces and ponds/reservoirs. Curve A shows that, under natural vegetation cover, water erosion increases from the origin to a peak at 400 mm annual rainfall, such as that in semiarid conditions. Near

[1]Paper presented at the U.S.A./Mexico Symposium on Strategies for Classification and Management of Native Vegetation for Food Production In Arid Zones. [Tucson, Arizona, October 12-16, 1987.] Aridland Watershed Management Research Unit. USDA-Agricultural Research Service, 2000 E. Allen Road, Tucson, AZ 85719.

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the peak (approximately at the transition between brush and grasslands) the precipitation is insufficient to maintain a complete year long vegetation cover but does produce sufficient energy and rainfall excess to erode bare soils. With increasing precipitation, the natural vegetation cover increases (less bare soil would be expected) and water erosion decreases. Curve B indicates expected erosion under bare soil conditions. Comparison of curves A and B illustrates conceptually the difficulty of controlling water erosion in the arid and semiarid end of the precipitation spectrum, a phenomenon not extending into the more humid spectrum.

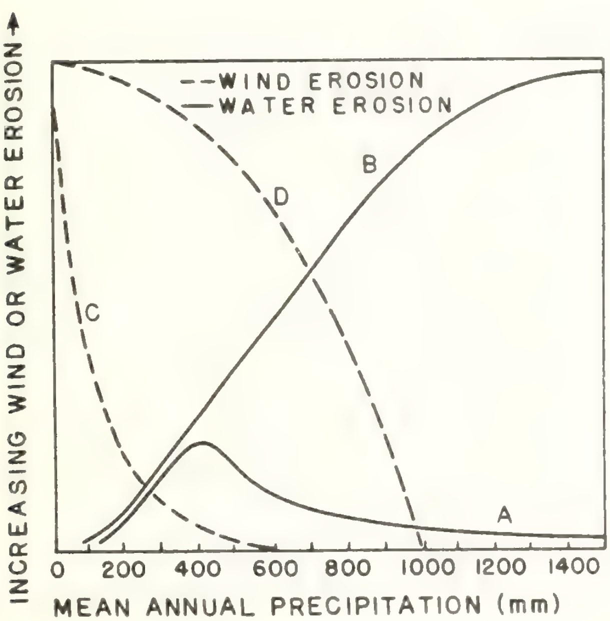

Figure 1. Relationships of water erosion (continuous lines) and wind erosion (broken lines) with increasing mean annual precipitation. The curves for water erosion indicate the relationships with mean annual precipitation for (A) areas of natural vegetation cover and (B) bare ground. The curves for wind erosion indicate the relationships with mean annual precipitation for (C) areas of natural vegetation cover and (D) bare ground. These curves are based on what would be expected from the relationship of wind erosion to vegetation cover and to moist soil (from Marshall 1973).

The schematic curves for wind erosion, curves C and D, differ appreciably from those for water erosion. Curve C depicts a rapid decrease in the normal wind erosion with increasing precipitation because the presence of even a moderately sparse vegetation cover would be expected to reduce the wind erosion shear at the ground surface. With the absence of vegetation (curve D), wind erosion would be expected to remain high until the precipitation increases sufficiently to keep the soil surface moist most of the time. The shape of curve D depends upon the amount of precipitation and its distribution and the curve would be expected to drop most steeply for a uniform distribution or a distribution where the moist soil coincides with periods of greatest wind. In contrast with water erosion, the greatest potential reduction of wind erosion (contrasting curves C and D) occurs in the drier precipitation areas.

In this paper, we intend to (1) present a proposed revised form for the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978); (2) illustrate how the revised form agrees with observed data in southeastern Arizona; and (3) illustrate with sensitivity analysis, the magnitude of erosion estimates by sequentially varying values of parameter terms in the subfactor approach for estimating the cover-management term.

REVISED USLE

Technology to assess erosion from rangelands is not as widely available as for cultivated agriculture. The technology generally involves the use of the USLE which was developed for more humid areas and then extrapolated to rangeland conditions. Developed from extensive field experiments, the USLE involves six terms, the product of which furnishes an estimate of the average annual erosion from a field area. The expression is

$$A = R * K * L * S * C * P \tag{1}$$

where A = computed soil loss per unit area; R = a rainfall and runoff factor; K = soil erodibility factor; L & S = topographic terms representing slope length and steepness; C = cover-management factor; and P = support practice factor.

Unfortunately, this technology was developed from experiments performed on cultivated areas; although the technology has been extended to most other land use conditions (Renard and Foster, 1985). In the current revision of the USLE, perhaps the most significant change occurs in the method used to determine a value of the cover-management factor, C. A subfactor approach is used, as proposed by Wischmeier, 1975, Mutchler et al., 1982 and Laflen et al., 1985. The factor C is expressed as

$$C = PLU * CC * SC * SR \tag{2}$$

where PLU is a prior land use subfactor, CC is a canopy subfactor, SC is a surface cover subfactor and SR is a surface roughness subfactor. Each of these subfactors in turn is also expressed by an equation so that a value can be computed for any specific situation. The equations contain the variables recognized to greatly influence erosion and vary according to land use and management practices.

The individual subfactor values presently proposed for rangeland are as follows:

$$PLU = (1\text{-}DY) * \exp(-0.012 * RS) \tag{3}$$

where $D = \frac{0.55}{T}$ and T is the total years over which a soil disturbance diminishes, Y is the years since disturbance, exp is an expression for

the base of the natural logarithm (2.718) raised to the power of the number following, and RS is the live roots and buried residue in the upper 100 mm of soil (kg per ha per mm of depth). When Y = T, the coefficient decreases to 0.45 which is the value of the soil loss ratio observed for a well consolidated soil. RS is not easily measured without destructive sampling and considerable manpower. Therefore, Equation 4 was developed so that RS could be estimated from above-ground biomass estimates.

$$RS = BIO * \eta_i * \alpha_i/100 \quad (4)$$

where BIO is the annual above ground biomass estimate (kg per ha), α_i is the ratio of below ground biomass to above ground biomass and η_i is the ratio of biomass in the upper 100 mm of soil to the total below ground biomass. Table 1 has been prepared for reported typical values of η_i and α_i by vegetation type (e.g. grass, brush, tree, etc.) which more or less corresponds to climatic region.

$$CC = 1 - FC * \exp(-0.34 * H) \quad (5)$$

where FC is the fraction of the land surface beneath canopy and H is the height (m) that raindrops fall after impacting the canopy.

$$SC = \exp(-4.0 * M) \quad (6)$$

where M is the fraction of the surface covered by nonerodible material (e.g. living and dead plant material, rock and large gravel). This factor is extremely important, especially where erosion pavement, cryptogams, or other nonerodible material protects bare soil from the erosive forces of raindrops or flowing water or both.

$$SR = \exp(-.026(RB-6)(1-\exp[-.035 * RS])) \quad (7)$$

where RB is a random roughness (mm) expressed as the standard deviation of surface elevations from a plane and is intended to reflect any tillage consequence or other roughness forms. These solutions for the equations presented herein as well as those for the other factors have been programmed for speedy solution in a user friendly way on a personal computer.

The soil erodibility value, K, as presented in the nomograph in Agriculture Handbook 537 will be left unchanged.

Other factors in the USLE have also been changed. For example, the R-factor data base which in Agriculture Handbook 537 (Wischmeier and Smith, 1978), was so inadequate for the western U.S., will be expanded to include about 1000 hourly precipitation stations. The R-factor analysis includes using site specific and

Table 1.--Mean values of η_i and α_i for use in calculating the root subfactor (RS) in the universal soil loss equation.

	η_i		α_i	
Vegetation type	Best Estimate	Range	Best Estimate	Range
Northern mixed prairie	0.34	0.219-0.770	1.12	0.636-119.610
Tallgrass prairie	0.74	0.730-0.753	2.08	0.230- 2.080
Shortgrass prairie	0.41	0.244-0.645	3.18	1.12- 10.465
Desert grasslands	0.38	0.364-0.394	2.28	1.976- 2.804
Lehmann lovegrass	0.63	0.320-0.626	2.73	2.500- 3.126
Annual grasslands	NA[1]	NA	NA	NA
Southeastern grasses and forbs	0.40	0.228-0.667	0.69	0.402- 1.520
Pinyon-Juniper	0.20	0.039-0.276	NA	NA
Sagebrush-bunchgrass	0.38	0.353-0.413	28.8	27.270- 29.600
Herbaceous interspaces	0.45	0.413-0.451	27.3	7.850- 27.266
Cold desert shrubs	0.46	NA	5.87	4.090- 11.000
Chaparral	0.13[2]	0.085-0.300	1.37	0.300- 1.900
Sandy shinnery oak	0.38	0.205-0.697	18.6	3.445- 18.589
Herbaceous interspaces	0.70	NA	5.48	NA
Southern desert shrubs	0.56	0.200-1.720	1.23	0.200- 18.35

[1]Data are not available.
[2]Root crowns and burls were excluded from root biomass calculations.

regionally developed correction factors. This approach adjusts hourly precipitation values to the EI_{30} that would be obtained from a recording gage with an expanded time scale similar to that used by Wischmeier and Smith in their original work (also called variable time digitization). The new isoerodent map for the western U.S. will have greater detail than that used heretofore. The correction for the approach on the Walnut Gulch Experimental Watershed in southeastern Arizona is:

$$EI_{30}(BP) = 0.215 + 1.956\ EI_{30}(60) \tag{8}$$

$$r^2 = 0.95,\ S.E.E. = 2.42$$

where $EI_{30}(BP)$ = kinetic energy x 30 min. maximum depth of rainfall based on a breakpoint hyetograph and $EI_{30}(60)$ = kinetic energy x 30 min. maximum depth of rainfall based on the record from an hourly recording.

Slope length and steepness (LS) for rangeland has been investigated extensively by McCool and Foster (personal communication) using research models and new field data. The nonlinear LS versus erosion relationship presented in Agriculture Handbook 537 (Equation 9) will be replaced with tables/algorithms (Equations 10, 11, and 12) for rangelands (and other land uses) reflecting the estimated intensity of rill to interrill erosion and the presence of erosion associated with thawing soil. Slope length and steepness were given in the original Handbook 537 as:

$$LS = \left(\frac{\lambda}{72.6}\right)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065) \tag{9}$$

where λ = slope length in feet;

θ = angle of slope; and

m = 0.5 if percent slope is 5 or more, 0.4 slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform slopes of less than 1 percent.

The term of Equation 9 is now replaced with:

$$LS_R = \left(\frac{\lambda}{72.6}\right)^m (10.0 \sin\theta + 0.027) \quad S \le 8\% \tag{10}$$

$$LS_R = \left(\frac{\lambda}{72.6}\right)^m (17.2 \sin\theta - 0.55) \quad S \ge 8\% \tag{11}$$

where LS_R = revised topographic factor, and

λ = horizontal projection of a slope

s = slope in percent

The slope lengths exponent m is related to the ratio β of rill erosion (caused by shear of flow) to interrill erosion (caused primarily by raindrop impact), by the equation (Foster, et al., 1977):

$$m = \beta/(1+\beta)$$

Values of the ratio β are obtained from (McCool et al., 1985; unpublished material):

$$\beta = \left[\frac{E(r/i)(\sin\theta/0.0896)}{(2.96 \sin^{0.79}\theta + 0.56)}\right] \tag{12}$$

where $\sin\theta$ = slope angle

E(r/i) = ratio of rill to interrill erosion; use 1 when the soil is moderately susceptible to rill erosion relative to interrill erosion; use 0.5 when the rill erosion is slight relative to interrill erosion; and use 2 when rill erosion is high relative to interrill erosion.

Finally, the supporting practices factor, P, has never been adapted specifically to mechanical rangeland conservation practices like ripping, root plowing, contouring and chaining. These practices affect wind and water erosion in several ways, most importantly by removal (usually temporarily) of surface cover. That effect is and should be considered in the cover-management factor. The mechanical practice effects on the P-factor involve the rate, amount and direction of runoff as well as the hydraulic forces that the flowing water exerts on soil. A table of P-factor values for five common mechanical practices used on rangelands, was developed by incorporating an estimate of the surface disturbance, duration of effectiveness of the disturbance and the runoff reduction into a physically based simulation model, CREAMS (Knisel, 1980). Simulations were performed for different slope steepness with the result that the table 2 values were adjusted internally in the computer program to reflect the slope steepness differences used in the program. Furthermore, 15 different scenarios for mechanical practices which alter roughness and runoff and are dependent on slope steepness are included in the computer program. This work was not used in the subsequent testing reported in this paper.

Table 2. Erosion Control Practice Values for Rangeland

Practice	P-Factor
Contour (1-16% slope)	0.60
Contour (17-25% slope)	0.85
Terraces (sod channel outlets)	0.14
Terraces (underground outlets)	0.05
Rootplow on countours	0.13
No practice	1.00

DATA BASE

The Agricultural Research Service of the U.S. Department of Agriculture maintains the 150 square kilometer Walnut Gulch Experimental Watershed in and around Tombstone, Arizona (fig. 2). The watershed is representative of millions of hectares of brush and grass rangeland found

throughout the semiarid Southwest. Major vegetation on the watershed includes creosote bush (*Larrea divaricata*), whitethorn (*Acacia constricta*, tarbush (*Flourensia cernua)*, black grama (*Bouteloua eriopoda*), blue grama (*Bouteloua gracillas*), tobosagrass (*Hilaria mutica*), and bush muhly (*Muhlenbergia porteri*). Typically, plant canopy averages 50 percent and plant basal area averages 2 percent. Average annual precipitation on the watershed is about 300 mm, and is bimodally distributed, with approximately 70 percent occurring during the summer thunderstorm season of July through September when essentially all of the runoff occurs. General watershed characteristics and results of the research programs were described by Renard (1970, 1977).

Erosion data have been collected on the Walnut Gulch Watershed using a rotating boom (Swanson, 1965) rainfall simulator (Simanton and Renard, 1982 and 1986).

The soils at the three simulator sites have been reclassified and new series descriptions are being prepared by the USDA Soil Conservation Service. The old Cave, Hathaway, and Bernardino soil series (Gelderman, 1970) have been proposed in the new soil survey as the Bactor (loamy-skeletal, mixed, thermic Ustollic Calciorthid), Stronghold (coarse-loamy, mixed, thermic Ustollic Calciorthid), and Abrigo (fine-loamy, mixed, thermic Ustollic Hapargid) series, respectively. Slopes on the rainfall simulation plots ranged from 9-11%, 10-12%, and 10-12% for the Bactor gravelly loam, Stronghold gravelly sandy clay loam, and the Abrigo very gravelly sandy loam series, respectively. The ground surface cover of all three sites is dominated by erosion pavement (rock and gravel typically occupy 40-60% of the soil surface).

At each simulator site, three surface conditions were evaluated: natural plots; plots wherein the vegetation was clipped at the plot surface and removed; and bare plots where the vegetation was clipped and the erosion pavement along with all litter removed. Furthermore, the simulation sequence involved an application of one hour at a rate of approximately 60 mm on day one followed by a 1/2 hour application 24 hours after the first run and a second 1/2 hour 60 mm/hr application about a half hour after the second run. Thus, the three simulation periods are called dry, wet and very wet runs indicative of antecedent soil moisture conditions. The simulations were also continued in the spring and fall over a four-year period (Simanton and Renard 1986). Differences in the temporal characteristics of erosion and runoff were appreciable for the treatments of clipping, bare and natural plots for all three soil sites although the trends were not consistent across the soil types (Simanton and Renard, 1986).

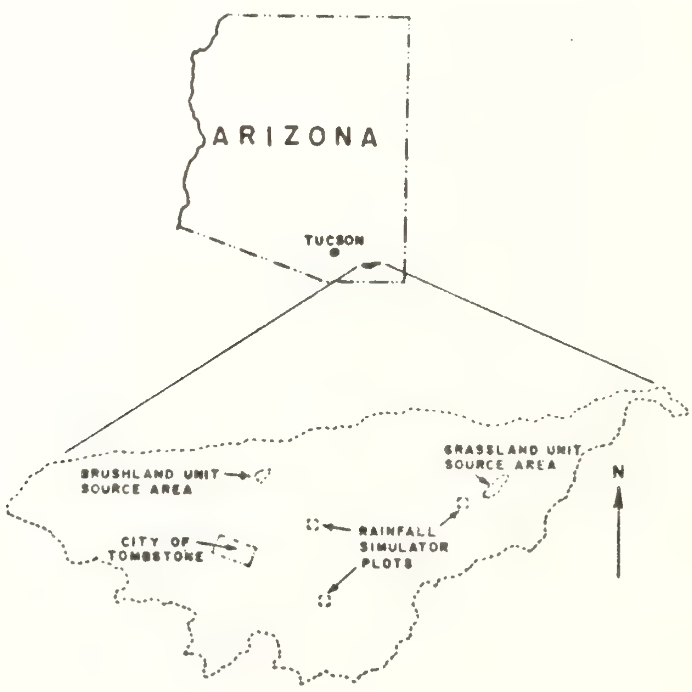

Figure 2. Location map showing the rainfall simulator plots in the Walnut Gulch Experimental Watershed.

CORRELATION OF PREDICTED AND OBSERVED SOIL LOSS

Some of the data from Walnut Gulch contained in Appendix A (Simanton et al., 1986) of the Proceedings of the Rainfall Simulator Workshop, January 1985, Tucson, Arizona, were used as input to predict erosion with the proposed revision of the USLE as well as with the procedure outlined in Agriculture Handbook 537. To facilitate the computations, a computer program was written which permitted easy computations for the algorithms expressed in Equations 1 to 7 and Equations 10 to 12. The program is available upon request to the authors.

Because the erosion was much larger from the bare plots and because the vegetation and erosion pavement removal disturbed the soil surface of these plots, special care was made to account for differences between the predicted and observed bare plot soil loss. The effort involved evaluation of the coefficient of the exponential decay in the PLU (prior land use) term in the subfactor approach (equation 3). Observation of the data previously reported by Simanton and Renard (1986) showed that the disturbance lasted about 2 1/2 years. Thus the D term was assigned a value of 0.22 and the predictions made accordingly. The plot was kept free of vegetation by chemical control and only minimal disturbance occurred subsequently with rock removal.

Total root biomass measured near the site was 15,000 lbs/ac (Cox et al. 1986). The near surface fibrous root mass was 2,800 lbs/ac. Root crowns and deeper (> 4 in) large lateral roots comprised 81% of the total root mass. These deep roots contribute little to the stability of the soil surface and have no effect on surface erosion from raindrop impact and overland flow. Therefore, the near surface fibrous root mass value of 2,800 lbs/ac was used to initialize the RS subfactor for the first rainfall simulation runs on all three treatments. On the bare plots RS was reduced to 1,400 lbs/ac after 6 mo., 700 lbs/ac at the end of 1 year, and to 0 lbs/ac for the remainder of the study. On the clipped plots, the root mass was assumed to be 1,400 lbs/ac after the first year.

Table 3 lists regressions of predicted versus observed erosion for six different groupings of the simulator plot data. Data groupings #2 and 5 were made because of some questionable data on plot 4 in the spring of 1982.

In each instance, the slope of the line was less than unity indicating that the predicted values of soil loss (Handbook 537 procedure and proposed revised USLE) were less than the measured values. Comparison of data groups 3 and 6 showed that the new USLE which includes the subfactor approach to determining C and the new algorithms for the LS-factor give better estimates of soil loss than does Handbook 537. The new method also did not overpredict as often as did the Handbook 537 procedure for smaller soil loss conditions such as were obtained for the natural and clipped plots.

Table 3. Regression Analysis $Y = a(OBS_{SL})$ for Predicted vs. Observed Soil Loss

Group No.	Data	N	a	r^2
		Prediction with Handbook 537		
1	bare plots 1981, 82, 83, 84	96	0.586	0.389
2	#1 w/o spring 1982 on plot 4	94	0.643	0.529
3	#2 plus clipped & natural 1982 & 84	190	0.659	0.699
		Prediction with Revised USLE		
4	bare plots 1981, 82, 83, 84	96	0.712	0.348
5	#4 w/o spring 82 on plot 4	94	0.772	0.517
6	#5 plus clipped & natural, 1982 & 1984	190	0.768	0.766

SENSITIVITY ANALYSIS

To illustrate the sensitivity of the subfactor values, the individual parameter values RS, FC, H, M and RB contained in equations (3) to (7) were varied about the mean values used in the Bactor soil simulator plots. The results of the sensitivity analysis on the cover-management factor in the USLE are presented in figures 3a, b, c, d and e. Care must be used in interpreting these figures because of the differing scale used for the ordinate values.

The single most sensitive term is probably that associated with ground cover, figure 3d. This sensitivity might also be expected intuitively because the intensity of bare soil exposed to either the splash erosion of impacting raindrops or the shear of water moving over the soil surface or both are the major elements permitting erosion to occur. Although the amount of roots present in the upper 100 mm of the soil profile are also quite sensitive (fig. 3a), much of this change occurs near the origin, i.e., most of the change occurs when the root mass changes from about 0 to 4000 lbs/ac and might, therefore, be expected in connection with decomposition of annual roots within a fallow field rotation and/or tillage activity, factors not encountered in normal range practices. The other factors, shown in figures 3b, c, and e, are not specially sensitive on an annual basis or at a specific site associated with land use or management.

CONCLUSIONS

A new procedure has been presented to estimate soil loss resulting from water erosion on rangelands. The procedure involves a more realistic approach for estimating the cover-management factor in the USLE involving

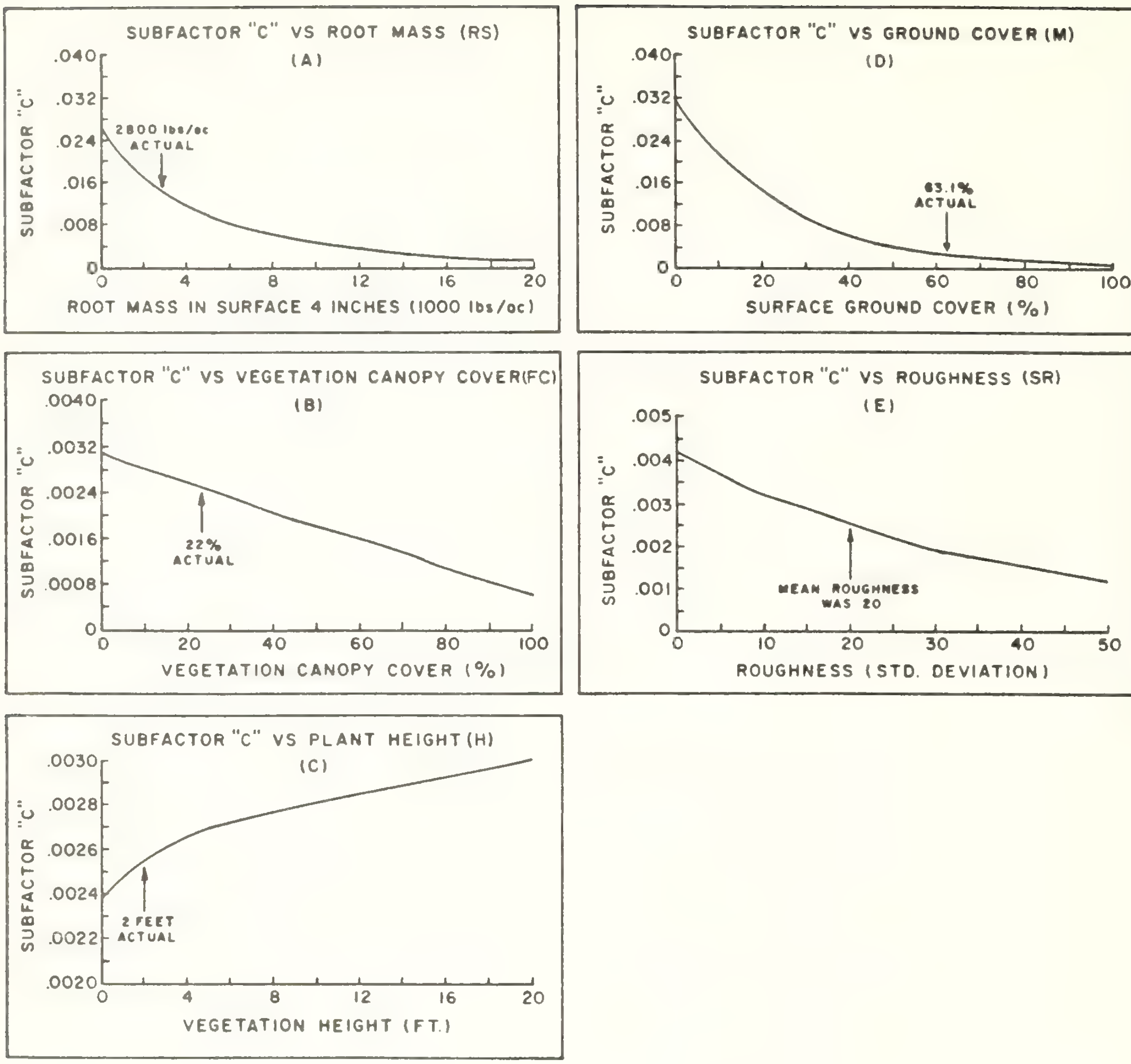

Figure 3. Sensitivity analysis for the cover-management subfactor.

consideration of prior land use, crop canopy, surface cover (including erosion pavement and cryptogams) and surface roughness. The prior land use and the surface roughness terms require information on the root mass in the upper 4 inches (100 mm) of the soil profile, a value not easily obtained without destructive sampling and extensive labor efforts. Root biomass can be estimated from above-ground biomass data using previously published data to relate above- to below-ground biomass. The table can be used in the absence of actual measurements.

The slope of a line through the origin for observed and predicted soil loss indicates that the predicted values (both with Handbook 537 and the revised USLE) underpredicted measured erosion on a series of plots in southeastern Arizona on three different soils. However, the predictions were substantially improved using the revised USLE method.

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Nitrogen Enrichment Effects on Vegetation of a Northern Chihuahuan Desert Landscape[1]

Joe M. Cornelius and Gary L. Cunningham[2]

Abstract.--A large scale experiment was conducted at the NSF/LTER Jornada site examining enrichment effects of a limiting resource (nitrogen) across a desert landscape. Results showed increased cover of ephemeral plant species and decreased species diversity in response to increased nitrogen, probably due to changes in availability ratios of limiting resources and decreased heterogeneity in the spatial distribution of soil nitrogen.

INTRODUCTION

The conversion of desert grasslands to shrublands of much lower grazing potential has been well documented in much of the southwestern United States and northern Mexico. This conversion, or desertification, has long been recognized as being both a cause and effect of increased erosion. This erosion results in alterations of the spatial and temporal pattern of water and inorganic nutrients. It can thus affect patterns of primary production and the structure of vegetation. The historical records, though meager, indicate that the desert grasslands were relatively uniform and homogeneous over extensive areas that traversed a variety of landforms and soil types. The present vegetation is more heterogeneous and patchy. These former grasslands are now a mosaic of various shrub dominated vegetation types interspersed with areas dominated by forbs and annual grasses, as well as apparent remnants of the original perennial grass dominated vegetation. It is reasonable to hypothesize that this mosaic structure of the vegetation is a result of non-uniform spatial distributions of limiting resources that have resulted from increased erosion in the desertification process.

The traditional view of arid regions has been that ecosystem processes (eg., primary production, decomposition, population dynamics, etc.) are primarily controlled by patterns of water availability (Noy-Meir 1973). However, recent studies in the northern Chihuahuan Desert (Ettershank et al. 1978, Gutierrez and Whitford 1987, Ludwig et al. 1987) have demonstrated nitrogen availability can be limiting, and thus controlling, during periods of adequate soil moisture. These studies suggest that interrelationships of water and nitrogen availability need to be considered in order to understand arid ecosystem processes (Whitford 1986, Whitford et al. 1987).

Wondzell et al (1987a) discuss how patterns of landscape features and substrate composition may affect the flow of water, organic matter and nutrients across a landscape, which result in accumulation or loss of resources within individual landscape units. They also demonstrate how landscape features affect the relative stability of various landscape units and their susceptibility to desertification causing factors. These processes result in the formation of different biotic zones across a landscape, that can each respond differently to pertubations and disturbances, as well as management practices.

The importance of nitrogen as a limiting resource in the Chihuahuan Desert, and the importance of landscape features in affecting the transport of water, organic matter and nutrients between landscape units, and the stability of individual landscape elements, lead to several community level hypotheses relative to vegetation dynamics. First, nitrogen fertilizer amendment to an entire Chihuahuan Desert landscape should result in an increase in overall plant productivity. Second, addition of nitrogen should change the relative ratios of limiting resources within the ecosystem, which should affect community structure by favoring those species most limited by nitrogen availability, causing a reduction in plant community diversity (Tilman 1982). Third, effects of increased nitrogen should vary between different landscape units, depending

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[1]Paper presented at the symposium on strategies for classification and management of native vegetation for food production in arid zones. [Forest Service, USDA Rocky Mountain Forest and Range Experiment Station, Tuscon, Arizona, October 12-16, 1987].

[2]Joe M. Cornelius, Research Assistant, Gary L. Cunningham, Professor, Department of Biology, New Mexico State University, Las Cruces, NM. This research was supported in part by NSF grant BSR 814466 to the LTER Jornada Program.

upon the type of vegetation occurring on them, their stability, and the degree to which they have been impacted by desertification.

METHODS

To examine these hypotheses, a large scale nitrogen amendment experiment was conducted on the National Science Foundation / Long-Term Ecological Research (NSF/LTER) Jornada Site located on the New Mexico State University College Ranch approximately 40 km N of Las Cruces, New Mexico. The site is located in the Jornada del Muerto basin at the northern edge of the Chihuahuan Desert. The Jornada basin was dominated by desert grassland vegetation prior to the 1900's, but, has since been mostly desertified to desert scrub vegetation (Buffington and Herbel 1965, York and Dick-Peddie 1969, Sallach 1986). Regional climate is arid to semi-arid with a mean annual precipitation of 215 mm, and, is characterized by three distinct seasons (table 1): 1) hot-dry springs (April-June), 2) hot-wet summers (July-October), and 3) cool-dry winters (November-March) (Walt Conley, unpublished data; Pieper et al. 1983). Intra-seasonal and intra- and inter-annual rainfall patterns are all highly variable in space and time, and droughts are common phenomena (Neilson 1986)

Two parallel (70 m apart) 2.7 km transects were established in 1981 ranging from a lower piedmont-slope fan collar at the base of Summerford Mountain in the Dona Ana Mountains (upper transect elevation ca 1410 m) to a small playa basin (elevation ca 1300 m). The site was heavily grazed in the late 1800's to the early 1900's. Since the 1920's the site has had a moderate to light grazing history, and, has not been grazed since establishment of the LTER site in 1981. Permanent sampling stations were established at 30 m intervals along each transect. Plant species cover was estimated for each station every spring and fall 1982-1986 during times of maximum plant cover. A 30 m wide strip centered on one transect was amended with nitrogen (N) fertilizer (30 g NH_4NO_3 (10 g N) m^{-2}, applied by airplane) in August 1983, August 1984, March 1985, August 1985 and July 1986.

TABLE 1. Seasonal distribution of rainfall (mm) at the NSF/LTER Jornada Site 1982-1986. Average is based on 1941-70 NOAA Jornada Experimental Range weather data.

YEAR	WINTER	SPRING	SUMMER	TOTAL
1982	35.8	13.8	125.4	175.0
1983	56.2	38.1	126.7	221.0
1984	26.9	68.8	219.5	315.2
1985	133.5	16.1	272.2	421.8
1986	27.9	20.3	143.0	215.1
AVERAGE	51.8	20.3	143.0	215.1

TABLE 2. Fall cover of photosynthetic pathway / life-form / growth habit functional groups by vegetation zone. Values are means of 1982-1986 untreated transect data. Vegetation zones are defined in the text.

	VEGETATION ZONE					
GROUP$	1	2	3	4	5	6
C_3SH	0.0	29.3	3.2	24.7	5.6	4.2
C_3SS	0.1	5.7	6.3	4.8	5.2	1.3
CAM	0.0	0.0	0.1	0.4	3.3	3.5
C_4PG	40.3	20.1	8.7	4.8	22.3	42.2
C_3PF	27.9	3.5	6.7	2.1	3.2	1.9
C_4PF	0.1	0.7	1.4	0.1	0.6	2.7
C_4AG	<0.1	0.4	5.8	<0.1	7.3	3.9
C_3AF	9.6	3.5	5.6	3.8	8.5	7.7
C_4AF	3.4	9.1	18.2	1.1	3.2	4.8

$Functional groups are: $C_3SH=C_3$ shrubs; $C_3SS=C_3$ subshrubs; CAM=crassulacean acid metabolism perennial succulents; $C_4PG=C_4$ perennial grass; $C_3PF=C_3$ perennial forbs; $C_4PF=C_4$ perennial forbs; $C_4AG=C_4$ annual grass; $C_3AF=C_3$ annual forbs; $C_4AF=C_4$ annual forbs;

Species were grouped into functional group types based on similar methods of resource acquisition in time and space. Functional group definitions were based on a combination of photosynthetic pathway (CAM, C_3, or C_4) (determined from Syvertson et al. 1976, and Kemp and Gardetto 1982), life-form (perennial or annual), and growth habit (shrub, subshrub, grass, or forb). Species determinations and life-form and habit classification are from Correll and Johnston (1972). Functional groups occurring on the transect were C_3 perennial shrubs, C_3 perennial sub-shrubs, CAM perennial succulents, C_4 perennial grasses, C_3 perennial forbs, C_4 perennial forbs, C_4 annual grasses, C_3 annual forbs and C_4 annual forbs.

Several major vegetation zones based on perennial species cover have been identified along the topographic gradient traversed by the transects (Wierenga et al. 1987). In order of occurrence from the playa basin to the base of the mountain, the vegetation zones defined were (table 2): (1) Playa-dominated by C_4 perennial grasses and C_3 perennial forbs, (2) Playa Fringe-dominated by C_3 perennial shrubs and C_4 perennial grasses, (3) Mixed Basin Slopes-characterized by low overall cover and dominated by C_3 and C_4 annual and perennial forbs and C_4 perennial grasses, (4) Bajada Shrubland-dominated by C_3 perennial shrubs, (5) Lower Piedmont Grassland-dominated by C_4 perennial grasses (low overall

cover), (6) Upper Piedmont Grassland-dominated by C_4 perennial grasses (high overall cover). The Playa Fringe zone was omitted from analysis because this narrow zone had too small sample size. The Playa zone was also omitted from analysis because fertilization treatment effects were comfounded by flooding events (Wondzell et al. 1987b).

RESULTS AND DISSCUSSION

Large spatial and temporal differences in vegetative characteristics have been observed along the gradient (figure 1) due to a combination of effects from: 1) seasonal and annual variability in the occurrence and abundance of rainfall (table 1); 2) abiotic factors controlled by edaphic properties and/or landscape position (Wondzell et al 1987a, Wierenga et al. 1987); and 3) temporal variation in the physiological ability of different groups of species to respond to changes in abiotic variables. There has been a marked increase in C_4 perennial grass cover in all zones except the Bajada Shrubland zone during the first 5 years of monitoring. But, there has been no detectable change in C_4 perennial grass cover due to N amendment. C_3 subshrubs, C_3 perennial forbs, and C_4 perennial forbs have shown similar patterns of response, increasing in cover in most zones through time, but showing no response to N amendment.

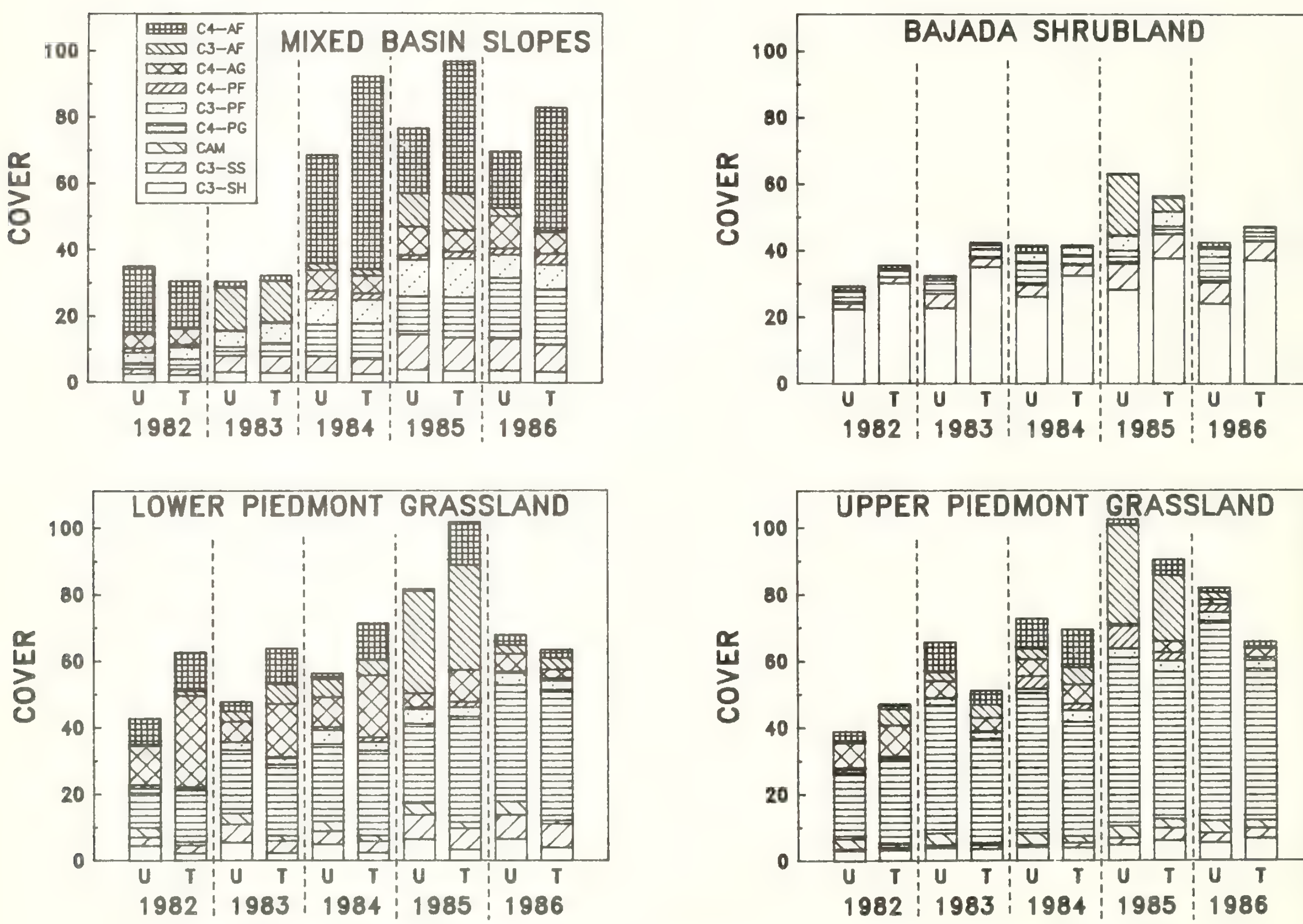

FIGURE 1. Fall 1982-86 cover of photosynthetic pathway / life-form / growth habit functional groups for the Mixed Basin Slopes, Bajada Shrubland, Lower Piedmont Grassland and Upper Piedmont Grassland vegetation zones. Abbreviations for functional groups are as follows: C4-AF=C_4 annual forbs, C3-AF=C_3 annual forbs, C4-AG=C_4 annual grasses, C4-PF=C_4 perennial forbs, C3-PF=C_3 perennial forbs, C4-PG=C_4 perennial grasses, CAM=crassulacean acid metabolism perennial succulents, C3-SS=C_3 subshrubs, and C3-SH=C_3 shrubs. U=untreated transect, T=NH_4NO_3 treated transect

The only measurable vegetation response to N amendment observed to date is an increase in cover by ephemeral plant species on the treated transect (figure 1). This has occurred in both spring flowering C_3 annual forbs (table 3) and summer flowering C_3 and C_4 annual forbs (fig. 1). However, the response has been large enough that it is detectable at the level of the entire landscape in overall gradient species diversity components, with decreases occurring in alpha, beta and gamma diversity on the treated transect (table 4). The changes in diversity are due to a small number of species increasing greatly in abundance in response to increased N. At the level of individual vegetation zones occurring along the gradient, only the Mixed Basin Slopes and Lower Piedmont Grassland zones, both characterized by low perennial cover, have shown a significant response to N amendment, exhibiting increased cover of annual species (figure 1, table 3) and decreased diversity (table 4). The Bajada Shrubland and Upper Piedmont Grassland vegetation zones, dominated by perennial species, have not shown a vegetation cover response to N amendment

These results allow a preliminary evaluation of the proposed hypotheses. An increase in overall productivity in response to N amendment did occur, however, it was only detectable for ephemeral species. There was a decrease in overall diversity in response to N addition (and changing of limiting resource ratios), as predicted by Tilman's (1982) "resource ratio-diversity" hypothesis. There were differences in response between vegetation zones (landscape units) along the transect, with the greatest magnitude of response (increased productivity, decreased diversity) occurring in zones characterized by low perennial cover (ie., dominated by ephemeral species). Zones characterized by low perennial cover also exhibited the greatest increase in perennial cover (especially grasses) over time, a recovery response from the grazing regime prior to exclusion from grazing. However, all vegetation zones, with the exception of the Bajada Shrubland zone, showed a significant increase in perennial grass cover through time.

TABLE 3. 1982-86 spring cover of C_3 annual forbs by transect treatment (TRT): N treated (T) and untreated (U).

		VEGETATION ZONE			
YEAR	TRT	ZONE 3	ZONE 4	ZONE 5	ZONE 6
1982	U	0.82	0.05	0.15	0.24
	T	0.96	0.02	0.74	0.20
1983	U	14.01	2.93	14.74***	32.46*
	T	12.24	1.35	27.28	24.78
1984	U	1.10	0.92	4.93	6.71
	T	0.48	0.26	1.28	1.56
1985	U	10.67***	8.95	12.63***	23.05
	T	16.81	7.39	29.78	22.22
1986	U	4.06	1.63	5.11**	13.15
	T	5.24	1.21	14.78	15.74

*$p<0.05$, **$p<0.01$, ***$p<0.001$

TABLE 4. Fall 1982-86 N_2 plant species diversity components (Peet 1974) for the overall gradient (alpha, beta and gamma) and within each zone (intra-zone diversity). Values were jackknife estimated according to Routledge (1980, 1984).

		GRADIENT DIVERSITY			INTRA-ZONE DIVERSITY			
YEAR	TRT$	ALPHA	BETA	GAMMA	3	4	5	6
1982	U	6.5	3.8	24.6	13.3	1.9	16.5	4.2
	T	5.1	3.8	19.1	14.7	1.4	8.8	3.6
1983	U	5.4	2.9	15.2	7.5	2.2	18.9	3.6
	T	4.8	3.1	14.8	9.4	1.5	14.1	3.3
1984	U	6.7*	4.0*	26.8*	17.2*	2.8	17.2	3.7
	T	5.2	3.2	16.6	9.9	1.7	13.1	5.2
1985	U	7.9*	3.4	27.1*	19.8*	4.2	11.7	4.2
	T	5.5	3.2	17.9	12.4	2.3	9.8	4.5
1986	U	7.0*	3.3	23.3*	16.6	3.3	13.2*	2.5
	T	5.3	3.5	18.9	14.8	6.4	5.9	2.6

$TRT=treatment: U=untreated, T=N treated.

*Indicates no overlap in 0.95 confidence limits of estimates for treated and untreated transects.

Should the fact that no N amendment response was observed for C_4 perennial grasses be interpreted negatively from a management perspective? At first, this may appear to be the only interpretation possible. However, the method by which we measured response may be misleading. For instance, actual grass biomass production may have been greater on the treated transect, even though overall cover was the same. Also, N content of tissue may have been increased on the N amended transect. Both of these possible responses to N amendment, which were not examined in our study, would cause increased quality of grazing forage, even if overall cover was not increased.

The observed response of ephemeral species to N amendment could also be important from a range management perspective. The increase in C_3 annual forb cover in response to increased N in the spring results in an improvement in forage quality at a time of year when grass forage is unavailable or of low quality. Several of the C_3 annual species which increase cover in response to

increased N, also respond by increasing the N content of their tissues (Whitford 1986), which would also result in an improvement in forage quality.

Ecologically, the increase in ephemeral species production in response to N amendment should result in a gradual increase in soil organic carbon (C) and N. This increase in soil C and N, could, over an extended period of time, result in a more homogeneous spatial distribution of limiting resources, leading to an increase in the density, cover, and productivity of perennial grasses, effectively reversing the patchy distribution of resources, and thus vegetation, caused by desertification. However, the change could take many years to occur.

The process of recovery from overgrazing is frustratingly slow in arid regions. But, the evidence presented in this research does indicate that low productivity rangeland within our research area, caused by previous overgrazing, can recover within certain types of vegetation and certain landforms. The slow rate of recovery and the lack of dramatic productivity response to N amendment, particularly for perennial grass species, mean that the use of widespread N amendment is not economically feasible in arid lands. However, when management for recovery of intensively desertified arid lands becomes necessary, nitrogen needs to be considered.

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CORRECCION DE TORRENTERAS PARA LA PRODUCCION DE FORRAJES EN ZONAS ARIDAS[1]

Carlos A. Berlanga Reyes[2]

Resumen.- Se pretende manejar escurrimientos - mediante curvas-nivel, establecer plantas forraje-- ras deseables, controlar erosión; se obtuvieron re- sultados óptimos, desmontando para sembrar Cenchrus ciliaris en parte de superficie de curvas y ------- Atriplex canescens en las restantes. Obras de con- servación suelo-agua, preparación de terreno, asegu ran mayor éxito al resembrar plantas forrajeras y - mayor capacidad de carga de áreas degradadas.

INTRODUCCION

Es sabido de las grandes superfi--- cies consideradas como zonas áridas y -- semiáridas; muchos son los autores que - las han clasificado, ya sea de acuerdo a sus características físicas, de vegeta-- ción o climáticas, en sí, son grandes -- extensiones que ocupan alrededor del 25% de los Continentes (30 millones de km^2), y México por su situación geográfica se- encuentra comprendido entre estas áreas, apróximadamente el 45 % de su territorio posee las características climáticas tí- picas que se consideran, como son, preci pitación entre los 100 y 250 mm anuales, mala distribución de las lluvias durante el año y cubierta vegetal menor al 70 %- dominada principalmente por xerófitas.

Hablar de zonas áridas y semiáridas es pensar en parajes inhóspitos y desa-- lentadores, más la naturaleza ha selec-- cionado organismos vivos que toleran per fectamente las situaciones adversas con- hábitos característicos bien marcados, - existen tantas especies que por su uso - pueden agruparse en Industriales como -- lechuguilla, candelilla, cuayule, palmas, sotoles, etc. Medicinales, Forrajeras y Ornamentales como los cactus, por citar- algunos, el hombre en su afán de subsistir y el desconocimiento de técnicas de mane- jo, ha originado problemas destructivos y de consecuencias irreversibles en algunos casos.

Innumerables investigadores de estas áreas han tratado de combatir el proceso- de desertificación por medio de resiem--- bras con pastos y arbustos forrajeros con bastantes buenos resultados, aunque en -- algunos de los casos tenga que hacerse a- altos costos, son indispensables para la- recuperación de agostaderos y áreas degra dadas; por métodos naturales podría tar-- dar decenas de años en recuperarse o tal- vez continuar su proceso de deterioro si- no se emplea alguna técnica de manejo --- adecuada.

El Instituto Nacional de Investiga-- ciones Forestales y Agropecuarias a tra-- vés del Campo Experimental "La Sauceda",- Coahuila ha ensayado métodos de tratamien tos a el suelo y a la vegetación con el - propósito de establecer cubiertas vegeta- les mediante resiembras de gramíneas y -- arbustos forrajeros nativos e introduci-- dos, con resultados satisfactorios y alen tadores que inclusive ya han sido adopta- dos por Programas de Desarrollo de otras- Instituciones.

La finalidad del presente trabajo -- fue el de lograr manejar los escurrimien- tos o torrentes mediante el trazo de cur- vas a nivel, para el establecimiento de - plantas forrajeras deseables y controlar- la erosión.

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ANTECEDENTES

Heady 1975; Studart et. al. 1975, mencionan que el mejoramiento de la vegetación y de pastizales puede efectuarse por dos métodos: directo e indirecto.

El directo se caracteriza por la manipulación de la vegetación por medios píricos, mecánicos, químicos, modificaciones a la superficie del suelo y otros para la utilización de la precipitación "in situ".

De manera indirecta se puede hacer por métodos como: control del número y clase de animales, distribución de pastoreo, tamaño y forma de apotreramientos, etc.

El hecho es que en los dos casos anteriores el objetivo es estimular la sucesión del ecosistema hacia etapas de mayor productividad, considerando otros factores característicos de los ecosistemas en estudio.

Jabalera y Fierro (1977) definen la resiembra de agostaderos, como el proceso de establecimiento por medio de la diseminación artificial de semillas adaptadas. Comunmente usadas para rehabilitar pastizales degradados, zonas denudadas y agostaderos de baja productividad.

Elco (1972) dice que de seis especies que probó, el sorgo almum Sorghum almum es el más indicado para realizar siembras de pradera bajo riego, utilizándolo como única especie y los zacates garrapata Eragrostis superba, panizo azul Panicum antidotale, gigante Leptochloa dubia, banderilla Bouteloua curtipendula y azulado Panicum virgatum pueden ser utilizados en mezclas para resiembras de pastizales.

Echavarria (1973) dice que la resiembra en microcuencas o surcos muestra grandes perspectivas como práctica de mejoramiento de pastizales denudados, pues aunque su costo es ligeramente mayor que la siembra utilizando solamente rastra, disminuye los riesgos de fallas en el establecimiento de los zacates y logra una mayor producción de forraje y recuperación rápida de la inversión.

Aguirre y colaboradores (1976) probaron estructuras de captación para el establecimiento de gramíneas y arbustos en mezcla, observaron que las curvas a nivel resultan más eficientes un 72 % que el mejor tratamiento de picos.

Rodríguez, R. y colaboradores (1976) realizaron trabajos de resiembra y preparación de terreno con mezcla de cinco gramíneas y concluye que al efectuar la siembra después de desmontar y rastrear con tractor y solamente rastreo, la producción de materia seca fue superior 32.5 y 38.3 kg de materia seca/ha respectivamente, que sin realizar trabajos de ninguna especie (testigo) por efecto principalmente de la preparación de una cama de siembra más completa.

Flores (1980) trabajó con cinco gramíneas en mezcla en diferentes sistemas de cosecha de agua y concluye que, en cuanto a densidad, el mejor tratamiento es el de microcuencas con 160 plantas/m^2, en composición botánica sobresalió el sorgo almum Sorghum almum en poceo con 92 plantas/m^2, la producción ó rendimiento fue mayor haciendo poceo con 483.7 gr/m^2 y concluye que el poceo presenta las características más favorables en cuanto al establecimiento de pastizales de secano.

Ortega, R. y Guerrero, B. (1986) dicen que el zacate buffel Cenchrus ciliaris fue el que mejor se estableció de tres especies probadas en siembras para corregir torrenteras.

METODOLOGIA

Para desarrollar este trabajo se escogió un terreno de superficie aproximada a las 60 hectáreas en el Campo Experimental Forestal "La Sauceda" dentro del tipo de vegetación denominado Matorral Inerme-Parvifolio dominado por gobernadora Larrea tridentata y hojasén Flourencia cernua, nopal rastrero Opuntia rastrera y palma china Yucca filifera, cubierta vegetal menor al 70 %, coeficiente de agostadero de 45 hectáreas por unidad animal y pendiente uniforme del 2 %. En el área se encuentran tres pequeños arroyuelos o torrenteras que fueron tomados para su corrección mediante el trazo de curvas a nivel perpendicular al sentido de la escorrentía natural para cubrir el suelo de vegetación, para este caso con gramíneas y arbustivas forrajeras primeramente; se usaron también material nativo como son el caso de magueyes y nopales para darle una mayor consistencia a los bordos y que dado alguna época crítica de escasez de materia seca, sea empleado como forraje de emergencia.

Para realizar la resiembra de zacate se probaron tres áreas siembra-escurrimiento las que son 1:1, 2:1 y 1:2 lo que significa que la mitad de la superficie de la curva se desmonta y se siembra, y en la otra mitad se deja la vegetación existente como protección, en el segundo

caso (2:1) se desmonta y siembran dos terceras partes de la superficie de la curva y en una tercera parte se deja la vegetación existente; para el tercero (1:2) una tercera parte de la superficie se desmonta y siembra, y dos terceras partes se dejan con la vegetación existente o de escurrimiento.

Para la siembra de los arbustos forrajeros se realizó un desmonte selectivo en el área sin tratamiento al suelo y de donde se extrajeron los arbustos no deseados se sembraron arbustos forrajeros en maceta de vivero.

Previos trabajos a este, relacionados con siembras de pastos nativos e introducidos, se observó que presentan mayor adaptación y sobrevivencia los introducidos; se realizó la selección de los que mejor se comportaron y son: el sorgo almum Sorghum almum que es un zacate bianual que llega a alcanzar los 2 metros de altura, con sistema radicular profundo y rizomatoso, resistente a sequías, de rápido crecimiento con buenas condiciones de humedad y con alto rendimiento de materia seca. Zacate buffel Cenchrus ciliaris pasto amacollado de raíz fibrosa con rizomas, resistente a la sequía y variaciones de temperatura, su crecimiento es en los meses más calurosos y lluviosos del año aunque rebrota durante el invierno estimulado por lluvias eventuales y pastoreo, soporta el pastoreo intensivo. Panizo azul Panicum antidotale pasto perenne de apróximadamente 1.50 m de altura, con sistema radicular profundo, con coronas rizomatosas cortas y gruesas, de crecimiento rápido y produce grandes cantidades de forraje; sus tallos endurecen y lignifican rápidamente, por lo que es recomendable sea pastoreado o cortado antes de la floración.

La densidad de siembra empleada para estos zacates fue de cuatro a seis kilogramos por hectárea.

Los arbustos forrajeros que se utilizaron para este trabajo son costilla de vaca Atriplex canescens, saladillo Atriplex acanthocarpa, que son dos arbustos nativos con buen contenido protéico, Atriplex nummularia y Atriplex halimus que son arbustos introducidos.

RESULTADOS

Los resultados obtenidos indican que la relación área siembra-escurrimiento de 1:2 (una parte de siembra por dos partes de escurrimiento), es la mejor en cuanto al establecimiento de las especies de zacate incluídos en este estudio ya que la distribución del agua fue mas satisfactoria y se manifestó en la uniformidad del crecimiento del zacate a lo largo de la curva, con excepción de los torrentes en donde este alcanzó más altura y vigorosidad.

En cuanto al establecimiento de los zacates, el sorgo almum y buffel presentaron mayor sobrevivencia al primer año; al segundo el buffel y panizo azul se comportaron mejor, y el sorgo almum se restringió a las áreas de mayor escurrimiento y acumulación de agua. El zacate buffel cubrió paulatinamente en su mayoría la parte removida de la curva y las áreas donde se habían sembrado las otras dos especies mezclándose y desplazándolas inclusive a áreas con mayor acumulación de agua mostrando con el tiempo ser el mejor de los probados.

En cuanto a productividad de materia seca se realizaron cortes con intensidad al 60 % en muestreos de un metro cuadrado y se reportaron hasta 465 gramos por metro cuadrado de materia seca de zacate buffel, sin considerar tanto a sorgo almum y panizo azul por no ser significantes sus poblaciones.

De los arbustos forrajeros incluídos no se tomaron datos de producción pero el que mejor se estableció fue la costilla de vaca primeramente y Atriplex nummularia en segundo orden.

Los dos restantes no tuvieron el éxito que los dos anteriores.

Las especies consideradas para reforzar los bordos tuvieron buenos resultados de establecimiento y crecimiento además de compactar el suelo de estas para retenerlos y contener las escorrentías o torrentes.

En la actualidad otros programas y dependencias del Gobierno Federal en México, han mostrado interés en realizar este tipo de trabajos de manera más intensiva. Un caso muy palpable es el del Programa de Desarrollo de las Zonas Aridas dependiente de los Distritos de Desarrollo Rural de la Secretaría de Agricultura y Recursos Hidráulicos.

Ellos han trabajado en algunos ejidos del Estado de Coahuila de los que se citan algunos, en que la capacidad de carga era superior a 60 hectáreas por unidad animal.

Ejido La Paloma, Ejido Nacapa, Noria de la Sabina, Independencia y otros en donde el coeficiente de agostadero se ha reducido considerablemente.

En el Ejido Plan de Guadalupe se cercaron 520 has de las que se sembraron 196 con pastos, y redujeron su coeficien-

te de agostadero de 70 hectáreas por unidad animal a menos de 26, esto significa un logro satisfactorio, ya que inclusive se les ha otorgado un crédito para introducir ganado mayor. (Gómez, com. per. 1987).

El Centro Internacional de Investigación para el Desarrollo, (Canadá, CIID) en convenio con el INIFAP ha establecido módulos de producción rural en diversos ejidos de Coahuila y San Luis Potosí, en los que ha incluído este tipo de trabajos donde realizan desmonte, rastreo y siembra de zacates en la tercera parte de la superficie de las curvas, plantación de nopal como retenedor de bordos y desmonte selectivo en el resto de la superficie para plantación de arbustos forrajeros. Han obtenido resultados satisfactorios de producción de materia seca de zacates con 2324 kg/ha y 637 kg/ha de arbustos forrajeros susceptibles de aprovechamiento. (Reyes, CH. J. 1987)

CONCLUSIONES Y RECOMENDACIONES

La resiembra de zacates y arbustos forrajeros para producción de materia seca es conveniente realizarla en áreas degradadas, teniendo en cuenta algunos factores involucrados en el ecosistema.

Es conveniente realizar obras de conservación de suelos y agua como las curvas a nivel y preparación de una cama de siembra con el propósito de asegurar el éxito de la resiembra con zacates y arbustos forrajeros, esto redunda en una mayor densidad de plantas deseables y consecuentemente en una mayor capacidad de carga animal en los agostaderos.

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MANEJO DE SUELOS SALINOS Y SALINO-SODICOS[1]

Gustavo J. Lara Guajardo[2]

Resumen.- Debido al alto índice de tierras con problemas de sales indeseables, que con frecuencia nos plantean serios problemas en el desarrollo vegetal y consecuentemente en la productividad, conscientes de esto, surge la necesidad de la utilización de metodologías físicas y biológicas para la utilización y rehabilitación de estas áreas a corto y mediano plazo.

INTRODUCCION

Las tierras áridas y semiáridas de México, constituyen para el país un problema de gran magnitud, debido a que ocupan más de la mitad del territorio nacional.

Se estima apróximadamente un 60% de estas tierras con problemas de concentraciones de sales indeseables, tales como la de sodio que con frecuencia plantea problemas en el desarrollo agrícola, aunado a ésto el exceso de las mismas limitan el crecimiento vegetal y consecuentemente la productividad.

Como se sabe, las sales se encuentran en la solución del suelo, formando las sales solubles que se pueden extraer con obras de drenaje o succión, mientras que las que se encuentran en las arcillas (de origen intercambiable), si no exceden de un 15% en su concentración, representan un problema serio de rehabilitación.

Por lo anterior, estas extensas regiones a la fecha casi improductivas, representan un reto para el INIFAP, al realizar estudios para la rehabilitación e incorporación de estas áreas a la economía nacional.

[1]Documento presentado en el Simposio Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas.
Tucson, Arizona. U.S.A.
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OBJETIVOS

Cabe mencionar que el método a utilizar en este trabajo queda comprendido dentro de los biológicos mediante la utilización de las especies halófitas, en este caso *Atriplex canescens*.

El presente estudio pretende la recuperación y rehabilitación de áreas con problemas de sales, mediante la utilización de métodos físicos y biológicos con *Atriplex canescens* para la incorporación de estas vastas superficies a la economía nacional.

ANTECEDENTES

La acumulación de sales se asocia a procesos naturales o inducidos que propician las condiciones de ensalitramiento, si las sales liberadas por las rocas y minerales primarios permanecieran en su lugar de origen, los problemas de salinidad y/o sodicidad no se extrapolarían; el problema se genera cuando las sales se transportan y provocan acumulaciones en áreas o estratos asociados con otros problemas del suelo.

Clasificación de los suelos con problemas de sales

A inicios del siglo sobre la clasificación de suelos ensalitrados, Hilgard los dividió en álcali blanco (tipo salino) y alcali negro (tipo sódico); posteriormente Gedroiz utilizó los siguientes términos:

Suelos Salinos.

Son los que contienen suficientes sales solubles que interfieran en el crecimiento de plantas cultivadas, donde los valores de conductividad eléctrica del extracto de suturación son mayores

de 4 mmh os/cm, el porcentaje de sodio intercambiable es menor del 15% y su pH menor de 8.5; acumulación de sales como cloruro de sodio, sulfato de calcio, cloruro de calcio, en sus características físicas, con suelos de regular drenaje y regularmente defloculados cuando las sales se presentan en porcentajes muy elevados.

Suelos Sódicos.

Contienen cantidades en exceso de sodio intercambiable, los valores de conductividad eléctrica son menores de 4 mmh os/cm, su pH fluctúa entre 8.5 - 10 y su porciento de sodio intercambiable excede el 15% con escasa presencia de sales solubles, son suelos de baja permeabilidad y forman capas duras al precipitarse el carbonato de calcio ($CaCO_3$).

Suelos Salinos-Sódicos.

Tienen la misma apariencia y propiedades de los suelos salinos, mientras exista exceso de sales solubles con la particularidad de permanecer floculados; pero al producirse lavado o lixiviación de sales por lluvias o riegos, se transforman en suelos sódicos.

En relación a propiedades químicas, el resultado de la combinación de los procesos de salinización y sodificación, presentan propiedades químicas de suelos salinos y sódicos donde la conductividad eléctrica es mayor de 4 mmh os/cm, los valores de pH menores de 8.5 y la acumulación de sodio intercambiable mayor del 15% con relación al resto de cationes intercambiables.

Efectos de las sales durante el desarrollo fisiológico de las plantas.

El desarrollo vegetal es una función del efecto total de la humedad del suelo y éste es la suma de la presión osmótica provocada por sales y de la tensión superficial con la que el agua es retenida por las partículas del suelo, es importante mantener estos estados en los niveles más bajos, para su adecuado desarrollo de las plantas. Ahora bien, la presión osmótica se hace bajar mediante el lavado de las sales y la tensión superficial se disminuye proporcionando al suelo la humedad adecuada.

Entonces, los efectos que producen las sales en el desarrollo de las plantas son:

- Aumentar la presión osmótica de la solución del suelo, realizando la planta un mayor esfuerzo para absorber el agua.

- Acumulación de iones que en concentraciones bajas causan toxicidad a las plantas, como el boro, litio, etc.

- Limitar la nutrición mineral de las plantas, ya que la presencia de sales inhiben su desarrollo.

- Se produce una deshidratación gradual de la planta (protoplasma) abatiendo su desarrollo fisiológico por el gasto de energía para absorber agua.

Mejoramiento de suelos con presencia de sales.

La recuperación de suelos salinos propicia el mejoramiento de sus condiciones físicas, químicas y biológicas para el mejor desarrollo de plantas e incremento del rendimiento potencial.

Actualmente, se cuenta con una metodología diversa para resolver estos problemas; en esta ocasión nos referimos a la información más elemental; se tienen procedimientos que se basan en procesos sencillos, siendo los siguientes:

Métodos físicos.

Se involucran prácticas agrícolas que eficientizan un manejo adecuado del suelo.

Métodos químicos.

Adición de substancias y/o compuestos químicos, llamados mejoradores o correctores, que proveen calcio soluble reemplazando al sodio en la fracción coloidal; con ello, se neutraliza el pH y se hace reaccionar al $NaCO_3$ libre. Estos a su vez se dividen en:

- Sales cálcicas solubles: yeso, cloruro de calcio, etc.

- Compuestos cálcicos de baja solubilidad calcita, dolomita, etc.

- Acidos/formadores de ácidos: azufre, ácido sulfurico, etc.

- Acondicionadores de suelos sódicos: CDR-186 ó Krillium, carbón, etc.

Métodos hidrotécnicos.

Mediante lavado y drenaje se eliminan sales presentes en la capa superficial y posteriormente del área afectada.

Con el lavado de suelos se remueven sales de la zona radicular, mediante agua de riego con ó sin el drenaje artificial. Existen resultados donde el lavado es un método excelente para suelos salinos y en cambio, en suelos salino-sódicos y sódicos es un complemento.

Métodos químicos hidrotécnicos.

Empleo de aguas salinas para recuperar suelos sódicos, utilizando principios de lavado y desplazamiento de sodio intercambiable para accionar la floculación del suelo.

Métodos biológicos.

Adición de materia orgánica al suelo y/o establecimiento de plantas.

Y por último, Método eléctrico

Procesos y principios electro-químicos como electro-diálisis, electro-ósmosis, que se producen al pasar corriente eléctrica en un suelo saturado provocando la desalinización y desodificación del suelo ó sea la remoción de sales.

Cabe mencionar, que el método a utilizar en este trabajo se comprende en los biológicos mediante la utilización de halófitas, en este caso *Atriplex canescens*.

Descripción

La planta de *Atriplex canescens* (Pursh) -- Nutt, se conoce al norte de la República Mexicana como costilla de vaca, chamizo y cenizo, es un arbusto siempre verde, erecto, ramificado, leñoso de 0.40 - 2.5 m de altura con hojas numerosas, alternas, sésiles o cortopecioladas, en forma de espátula, oblongas o lineales, raramente elípticas, con forma de cuña en la base y obtusa en el ápice, 1.5 cm de largo, 0.2 - 1 cm de ancho, una nervadura espesa, superficie densa, de color gris costroso arriba y abajo, (Gloria y Pérez 1982, Briton y Brown 1970). La floración ocurre de junio a septiembre, son dióicas, raramente monóicas, con espiguillas densas que terminan en panículas grandes.

Uso Actual

Para balancear la alimentación del ganado.

De la Cruz, (1979), estudió la utilización de la costilla de vaca *Atriplex canescens*, en la alimentación de conejos de la raza Nueva Zelanda.

La costilla de vaca puede utilizarse como estabilizador de suelos salinos, por su buen desarrollo y la absorción de sal por la planta reduce los niveles de salinidad en el suelo.

Tamaño de la Semilla

El tamaño de la semilla varía en la misma planta así como de una planta a otra y de un sitio a otro. En estudios realizados por Springfield (1970), la longitud de la semilla varía de 2.2 mm a 09.4 mm y el grosor de las alas de 4.9 23.1 mm, el número de semillas por libra varía de 7,800 - 54,900 entre las semillas de ala y de 13,200 - 76,800 para las sin ala.

La semilla se produce en dos tipos de flores, una con orientación vertical de las brácteas y otra con orientación horizontal de las brácteas de la semilla, produciendo dos tipos de semilla, una pequeña dura, negra y otra grande y blanda de color café con diferentes características de longevidad y germinación.

Germinación

El contenido de cloruro de sodio en las brácteas de las hojas en niveles altos, puede impedir la germinación de semilla.

En estudios por Osmond, Bjorkman y Anderson (1980), con absorción de agua destilada, por las semillas y una solución de cloruro de sodio con potencial de agua de -21 bares, mostró que el incremento en peso verde se aumentó hasta el 70% , pero las que absorvieron agua destilada llegaron a 120%.

En la germinación ocurrió lo mismo, que las que absorvieron solución de cloruro de sodio tuvieron un 5% de germinación, las otras alcanzaron el 100%, todo esto en cuatro días, Beadle (1952), mostró que para 100% de germinación, en suelo nativo las especies de Atriplex requirieron el equivalente a 70 mm de precipitación pluvial.

La germinación también se afecta por los tipos de semilla; la semilla dura, pequeña y negra requiere menor cantidad de agua, tiene menor porcentaje de germinación, pero su longevidad es mayor mientras que en la blanda grande y café ocurre lo contrario.

La temperatura en la germinación es importante y Sharma (1976), obtuvo que la temperatura óptima para germinación fue de 20°C, con un porcentaje de germinación de 80% a 100% y con un potencial mátrico de -15 bares.

El oxígeno también es factor importante, se calcula en base a concentración del mismo más la mitad en embrión de sinapsis fue deficiente para la germinación en los casos en que el agua satura las bracteolas de algunas especies, ocurre una restricción en el cambio de gases o sea de oxígeno y produce la inhibición de germinación.

Habitat

La costilla de vaca es un arbusto, se encuentra en suelos con profundidades de más de un metro, se adapta a diversos tipos de suelos siendo más común encontrarla en suelos arenosos, areno-arcillosos, y franco arcillosos, salinos, calcáreos y alcalinos.

El desarrollo de esta planta ocurre en regiones con precipitaciones promedio de 220 mm (d) en adelante, aunque con 70 mm puede germinar.

Es tolerante a suelos con concentraciones medias y bajas en sales, la óptima concentración de cationes es de 50 meq/lt.

Su desarrollo ocurre mejor en suelos con pH superiores a 7.0, ya que en suelos con pH neutro su establecimiento es bajo, alrededor de 4.3%.

El contenido de minerales en la planta de costilla de vaca es el siguiente:

Minerales: fósforo 0.10 - 1.7%, calcio 0.6 - 1.49%, nitrógeno 0.9% y potasio 1.35%.

Digestibilidad

García (1980) en experimentos de digestibilidad de materia seca "in vitro" con cinco especies arbustivas del género Atriplex, resultó que las especies lentiformis y esponjiosa, al primer corte fueron las que mostraron mayor digestibilidad de materia seca con valores de 85.6% y 84.5% respectivamente, mientras que la especie halimus presentó 82.5%, la acanthocarpa 82.8% y la canescens obtuvo 81.3% de digestibilidad "in vitro" de la materia seca.

Cordoba (1974), analizó la digestibilidad "in vitro" y la composición química de varios arbustos y hierbas en Nuevo México; dentro de las arbustivas se analizó el A. canescens, con una digestibilidad promedio de 77%: el análisis se realizó de mayo a julio; la costilla de vaca superó en su porciento de digestibilidad a las demás arbustivas.

Consumo

Nasser (1977), menciona que A. canescens y otras especies de atriplex son el alimento de millones de animales cada año, de las regiones áridas y semiáridas del oeste de los E.U.A.

García (1981), observando los hábitos de consumo de las cabras, encontró que A. canescens tuvo mayor aceptación que otras especies de atriplex como A. acanthocarpa, A. halimus, A. lentiformis, siendo superada por gramíneas y hierbas.

Utilización

Atriplex canescens tiene en promedio de 10 a 20% de proteína, en las partes consumibles por el animal siendo comparable con la alfalfa Medicago sativa. La paladabilidad de costilla de vaca es buena para vacas, cabras y ovejas y en algunas especies silvestres. Preliminarmente las pruebas de digestibilidad "in vitro" indican buena digestibilidad (63.5%), aunque algunas especies de atriplex han sido reportadas con altos niveles de oxalatos, especialmente en suelos salinos, A. canescens mantiene bajos niveles tóxicos aún con incrementos en salinidad del suelo. La biomasa anual es buena, cercana a la de alfalfa, su recuperación a la presión pastoreo es excelente, a esta planta se le puede remover dos terceras partes de los brotes sin que se afecte la recuperación, su recuperación en sequías prolongadas es excelente y la tolerancia es excepcional, sin reducir productividad.

A. canescens es común de México a Canadá, sobrevive a temperaturas sobre los 40°C en verano y resite hasta -10°C en invierno.

En contenido de fósforo, los arbustos se consideran buenas fuentes de fósforo para el mantenimiento y gestación de animales en general, a menos que se encuentren en estado de madurez.

Arbustos como A. canescens no se consideran buenas fuentes de energía después que rebasan el estado fisiológico de fructificación.

A. canescens es consumida por cabras, ovejas, vacas y caballos, cuando otros alimentos escasean; los animales que más frecuentemente consumen esta planta son cabras.

Toxicidad

En toxicidad se analizan niveles de oxalatos y taninos, y Davis (1971) observó que en niveles de oxalatos, las plantas de invernaderos mostraron valores cercanos a los tóxicos (8.7%), el promedio de estos porcentajes fue de 6.4, las concentraciones de oxalatos en los tejidos en crecimiento antes de la maduración (6-9 meses) en invernadero presentan niveles de oxalatos cercanos a los tóxicos, pero luego descendieron marcadamente cuando la maduración fué avanzando.

Las plantas muestreadas fuera del invernadero nunca alcanzaron los niveles tóxicos, ya que en agosto mostraron 3.9% y en diciembre decreció hasta 0.9%.

Descripción del área de estudio

Localización geográfica

El Campo Experimental Forestal "La Sauceda" se encuentra ubicado en el municipio de Ramos Arizpe, Coahuila, aproximadamente a 100 kms de la ciudad de Saltillo, dicho campo se localiza dentro de las coordenadas 25°51' de latitud norte y 101°10' de longitud oeste del meridiano de Greenwich.

Superficie

Tiene la forma de un transecto, aproximadamente rectangular de 12,500 metros de largo y 800 metros de ancho ocupando una superficie aproximada de 1,000 hectáreas.

Vías de comunicación.

Cuenta con vías terrestres y aéreas, en donde las terrestres las constituyen los caminos de terracería, que parten del kilómetro 70 de la carretera Saltillo-Monclova con rumbo Suroeste y la otra sobre el kilómetro 65 de la carretera Saltillo-Torreón con rumbo Noroeste, se comunica también por el ferrocarril Monterrey-Torreón en la estación de Sauceda que se localiza al Sureste del campo a 500 m aproximadamente.

Además, cuenta con una pista corta de aviación sobre un lomerío en meseta.

Geología.

Las regiones donde se encuentra ubicada el área de estudio queda comprendida en las provincias geológicas denominadas Península de Coahuila, Golfo de Saginas, Cuenca de Parras, sistema orogénico transverso Torreón-Saltillo y Sierra Madre Oriental.

Geomorfología.

A nivel de micro-región, se localiza en el flanco oriental de la Sierra de la Paila, que en conjunto con la de la Palma, constituyen una sola estructura.

La máxima altitud topográfica dentro de la zona de estudio (2,600 msnm) se localiza en el punto topográfico denominado corazón del toro.

Topografía.

El campo está establecido bajo un transecto altitudinal de Noreste a Sureste en el flanco oriental de la Sierra de Paila, posee una forma de una franja de 12.5 km de largo por 800 m de ancho.

La pendiente en la cima varía de 2 a 3% y el 15 a 45 y en las laderas de las mismas mesetas la altura varia de 1,400 msnm en las mesetas altas, las medias con 1,300 msnm y las bajas con 1,250 msnm.

Hidrografía.

La zona de la Sauceda, queda dentro de la cuenca hidrológica del arroyo de patos.

Específicamente dentro de la subcuenca del arroyo del mimbre.

Vegetación.

La vegetación existente en el campo, es representativa de los principales tipos de vegetación en las zonas áridas de México y se puede distinguir básicamente las siguientes comunidades vegetales.

Matorral Inerme Parvifolio, formado por especies arbustivas de porte bajo y con ausencia de espinas.

Matorral Crasirosulifolio Espinoso, éste se caracteriza por la dominancia de especies crasas, arbustivas, de porte bajo y con sus hojas dispuestas en forma de roseta.

Bosque Oligocilindrocaule Rosulifolio, vegetación por especies con tallo cilíndrico sin ramificaciones en la base y con hojas dispuestas en forma de roseta, su principal componente es la palma samandoca *Yucca carnerosana*.

Clima.

El Campo Experimental, cuenta con una estación meteorológica en donde se han registrado por un período de 15 años los siguientes rubros:

Temperatura; las altas registradas en los últimos años es de 42.3°C, en los meses de abril a octubre, las mínimas de -17°C en los meses de enero a marzo, la temperatura media en éste período es de 18.9°C.

Lluvias; la distribución es muy errática -- pero por lo regular estas se presentan en los -- meses de mayo a septiembre, se han registrado -- años con pocas lluvias casi del total de precipitación anual, esto quiere decir, que son de origen torrenciales, la precipitación media es de - 193.71 mm.

Evaporación; ésta se presenta con mayor intensidad en los meses que registran las más altas temperaturas que son los de abril, mayo, junio y julio. La evaporación promedio es de 2,644. 71 mm.

Heladas; por lo regular se presentan en los meses de noviembre, diciembre, enero, febrero y las últimas en marzo.

Granizo; son muy reducidas las ocasiones en que se han registrado granizadas en dichas áreas y cuando esto ocurre se presentan en los meses - de mayo, junio y julio.

Nevada; éste fenómeno es de importancia media, ya que se han presentado nevadas irregulares en los últimos 15 años y cuando se han registrado son en los meses de noviembre, diciembre, enero y febrero.

Vientos; por lo regular la dominancia la -- tienen los vientos del Sureste (SE).

Clasificación del clima.

El clima predominante en el Campo Experimental Forestal "La Sauceda", es el muy seco o muy árido que de acuerdo a la clasificación climática de Koppen modificada por García, pertenece a la fórmula B''hw (E).

METODOLOGIA

El presente trabajo se desarrolló de acuerdo a las experiencias de estudios que se tienen respecto a la especie de Atriplex canescens, -- los cuales nos muestran que representa una alternativa viable para lograr con mayor éxito el establecimiento de una cubierta vegetal perenne - - siempre verde y con alto contenido de proteínas.

La metodología que se utilizó fue basada en resultados de las diferentes líneas de investigación, desarrolladas por el INIFAP, en donde - nos establece que para elmayor aprovechamiento - de las escasas y erráticas precipitaciones ocurridas en estas áreas, se realice el desmonte y paso de rastra como labores culturales, posteriormente se trazaron curvas a nivel para el levantamiento de bordos en donde la distancia entre ellas estuvo determinada por la fórmula del intervalo vertical, acto seguido se realizó el surcado en contorno, y por último la plantación en donde la distancia entre plantas es de 1.5m y de 1 m - entre surcos obteniéndose una densidad de 6600 - plantas por hectárea.

El material vegetativo fue producido en el vivero Arroyo de Patos perteneciente este al - - Campo Experimental Forestal "La Sauceda", en donde se seleccionaron individuos de altura y fenología similar para poder tener una mayor uniformidad en la plantación, esto se realizó en el -- mes de junio y julio del 84, precisamente en la época de lluvias.

Asimismo, con la finalidad de determinar producción de forraje en la plantación, se realizaron cortes de un 25 - 30% de la altura total de la planta después de 2 años de haber ocurrido la plantación, mismos que se realizaron dos veces - al año, uno durante el verano, y otra en invierno, y paralelamente a esto, se realizaron muestreos de suelo cada año, en donde se evaluaron - las características físico químicas y morfológicas del recurso suelo.

RESULTADOS

En lo que respecta al rubro de suelos se -- realizó una evaluación de los resultados de laboratorio en donde se detectó que para el año - de 1984, fecha en que se realizó la plantación, el suelo se caracterizaba por el alto contenido de sales, y sus contenidos de porciento de sodio intercambiable eran datos que no representaban - problemas serios de sodicidad, la fertilidad del suelo era baja y suelos de textura mediana, para el segundo año el del 85, se registró un considerable descenso en lo que respecta a la conductibilidad eléctrica, el cual nos indica una percolación de sales a horizontes más profundos y además nos indica que las demás características se mantuvieran estables en su mayoría, en el 86 se determina una modificación mínima en el pH del - suelo y porciento de fertilidad del mismo, pero en cuanto a la conductividad eléctrica si se encontró una considerable disminución del porcentaje de sales en los primeros 40 cm de profundidad, por último se determinó una estabilidad en lo que respecta al pH y un ascenso, aunque no de gran significacion de materia orgánica, pero cabe mencionar que si se registró la diferencia significativa del descenso de sales en el suelo, de --

acuerdo al período de observación se determinó que se encontró de la fecha de establecimiento a fines del trabajo, una diferencia de cuanto a la conductividad eléctrica de 1.41 mmhos cm, lo que significa que el porciento aproximado de extracción o remoción de sales en los primeros 40 cm es de 25% aproximadamente.

Y en lo que concierne al parámetro de producción de materia seca, se obtuvo en la última evaluación un promedio de 500 gr/planta en el primer corte realizado en verano, y un ligero descenso en la producción en el corte ocurrido en invierno a razón de 350 gr de materia seca por individuo. Esto debido a que la fenología de la planta que muestra mayor desarrollo en el verano que en el invierno, de acuerdo a las estimaciones realizadas se determinó que la producción promedio de materia seca por planta a razón de 800 gr, la cual nos arroja una producción estimada de 5280 kg/ha/año de materia seca. Cabe mencionar que esta producción se registró con individuos de una altura promedio de 1 metro y una cobertura de 200 m^2.

CONCLUSIONES Y RECOMENDACIONES

Por lo anteriormente expuesto se concluye que el realizar plantaciones de Atriplex canescens en suelos con altos contenidos de sales, muestra la alternativa viable para la utilización de estas tierras que hasta hace tiempo se consideraban casi improductivas, debido a que dicha especie posee la capacidad de extracción o remoción de las mismas, y a la vez mejorando la capacidad forrajera del área reforestada.

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Overpopulation, Desertification, Famine[1]

M. Anaya Garduño[2]

Abstract.--Desertification includes natural or induced processes. Poor nations suffer the greatest erosion problems Properly planned long-and-short-term management of natural resources through appropiate technology is crucial. Community participation is also of great importance, because the fight against desertification involves improving living conditions ina areas affected by misery, inemployment and underdevelopment.

Over the course of human development the rise and fall of several civilization has been intimately tied to the productivity of the land.

Some natural factors, like undesirable cultural practices and increasing population pressure, have provoked the impairment and destruction of the land's biological potential, reducing plant and animal productivity, and bringing on desertic conditions.

Many countries in Africa, Asia and Latin America are threatened by the dynamic deterioration of their natural resources. In some of them famine has already struck.

Desertification includes natural or induced processes which destroy the equilibrium of soil, vegetation, air and water systems. It is more pronounced in areas with a strong climatic or edaphic aridity, and constitutes a serious social and economic threat...desertification is a global expression of several processes.

Physical and biological soil damage may be caused by the misuse of natural resources or the foibles of nature.

There are seven processes which cause desertification: deterioration of the vegetation cover ...hydric erosion...eolic erosion...salinization. ..organic matter loss...crusting and soil compaction...and the accumulation of toxic substances in plants and animals.

[1]Paper presented at the simposium" Estrategias de Clasificación y Manejo de Vegetación Natural para la Producción de Alimentos en Zonas Aridas ".
Tucson-Arizona, E.E.U.U.; 12-16 October,1987.

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Arable land in the world comes to about 1.4 billion hectares, 21 million of which deteriorates each year with a total surface soil loss of 68,493 tons. Since the surface layer is the most fertile one, arable land is drastically and continuously reduced. In addition, 3 million hectares of non arable soil are lost every year.

World population increases by 80 million per year, so there is a constant challenge to rise unitary yields of basic grains to satisfy the growing demand for food products.

Estimates place the world population at 6.35 billion people by the year 2000, with a total cultivated area of 2.0 billion hectares under rainfed conditions and 302 million hectares under irrigation.

By then arable land in industrialized nations will amount to point four five (0.45) hectares per inhabitant, whereas developing countries will have at their disposal only two tenths of a hectare per person. This means that average basic grain yields will have to reach at least 2 3/4 tons per hectare to cover the demand for food.

Poor nations suffer the greatest erosion problems, and high population pressure, low availability of staple foods and low gross national product make Africa, Asia and Latin America the most critical areas.

Many nations hard hit by desertification lack integral planning for agricultural activities in rainfed, irrigated, pasture and forest land, resulting in the physical and biological destruction of these ecosystems.

Several African, Asian and Latin American nations have upwards of 60% of their population in rural areas. This menas thet they depend mainly on agriculture, animal husbandry, and forsstry for their livelihood.

The United Nations Environmental Programe estimates that 80% of the World's livestock areas are overgrazed, causing erosion and a consequent reduction in productivity.

Each year 1.8 billion cubic meters of trees are cut down for firewood world wide, equivalent to the energy of 5.5 million barrels of oil.

In South America, 83% of the rainfed areas show some degree of erosion, 23% of the irrigated areas have salinity problems, and 84% of the pasture lands are overgrazed.

In spite of possessing enough hydraulic resources, Latin America has several extremely arid zones, such as the Altar Desert of Mexico and the coastal deserts of Peru and Chile.

In Mexico, arid and semi-arid zones account for 56% of the national territory. There 10 million farmers have little possibility of working the land they were born on , and every year 600,000 move to urban areas.

About 150 million hectares of Mexican land roughly 75% of the national territory-shows some degree of desertification. From 150 to 200 thousand additional hectares are spoiled each year.

Among the many factors which produce desertification in Mexico, political decisions made solely in the interest of urbanization and industrialization take a heavy toll.

Mexico currently farms 22 million hectares of its land, 75% under rainfed conditions. This is a potentially dangerous situation since, given the projected population of 110 million by the year 2000 and an upper limit on farmable land of about 25 million hectares, the contry will have an average of only .23 hectares per capita at its desposal. If adequate measures are not taken, famine will surely result.

Enlisting technology in the fight against desertification is not easy. In regions with high population densities for example, the education and organization of local producers often proves so difficult as to be an insurmountable obstacle to new agronomic practices.

Properly planned long-and short-term management of natural resources through appropiate technology is crucial.

Community participation is also of great importance, because the fight against desertification involves improving living conditions in areas affected by misery, unemployment and underdevelopment.

No technology system, sophisticated or practical, will ever work unless special attention is given to education and training programs.

The selection and application of technology will depend on communities educational levels, as well as the money, time and quality technical personnel available for restoring affected lands

Three basic principles should govern the choice of technology to be used:

* First, the least affected production systems should be salvaged immediately, especially where severe financial limitations exist. In this way, relatively small investments will show good returns fairly soon. These in turn can be reinvested in more seriously affected areas, thus achieving a gradual improvement in productivity;

* Second, the use of intermediate technology should be stressed. since developing countries frequently have a reduced industrial capacity, poor transportation networks, credit limitations, and a development level which makes introducing advanced technology difficult.

* Third, traditional technology and community developed systems should be taken advantage of before introducing new land management techniques.

Even with careful application of both modern and traditional techniques, the soil may still suffer damage. This deterioration may result in one or several of five conditions: water scarcity, poor irrigation water explotation, a reduction in the vegetation cover and animal productivity, scarcity and misuse of energy sources, and soil erosion.

Rainfed areas with sloping terrain should take four basic steps in order to establish permanent production systems; first, control erosion; second, maximize rainfall utilization; third, improve soil fertility; and fourth, select the crop best to the given circunstances.

Rainfall utilization is an important way to fight desertification. Large scale application of available techniques is required to achieve optimum water use.

Runoff management is one of the most promising options. The ancient Nabateans of the Negev Desert in Israel were able to produce several crops in areas with only 100 mm of annual rainfall, using careful management techniques.

Recently, runoff control management has been used in Israel, Tunez, Australia, India, China, the Unites States and Mexico, augmenting yields of basic grains, vegetables and fruit trees.

Runoff control, canalization into small streams and water harvesting techniques help reduce erosion and improve water use efficiency.

The Nabateans also produced several crops in terraces and designed their own water havesting systems.

Most 20th-century nations have already begun soil conservation programs; many with promising results for reducing erosion under defferente production systems.

However, in some areas soil is being constantly eroded, especially where desperate people driven by hunger overexploit pasture and forest lands.

In order to prevent the advance of desertification, producers must be convinced of the importance of rational management of livestock and forest production in order to protect the vegetation cover.

Desertification in pasture lands can be avoided by a combination of several practices; for example: reseeding, fertilization, adequate grazing pressure and a good distribution of watering points to avoid excessive animal concentrations.

These practices have been successfully combined with crops systems under diverse social, economic and technological circunstances.

Unfortunately, rather than establishing well-defined production units, land tenure systems have encouraged overgrazing in pasture lands and actually blocked suitable management.

There are many places where the vegetation cover has been destroyed by over harvesting timber and firewood. In this way, man himself thwarts his best defense against desertification.

A better tactic would be to plant fast growing trees as a barricade against eolic and hydric erosion.

Other strategies to attack encroaching desertification may be suggested;

- Establishing long-and short-term programs in forest zones, pasture lands, rainfed and irrigated farmlands and areas under nomadic cultivation. Other land use systems are roads, national parks, human settlements and mines.

- Employing the watershed as an ecological and production unit concerted action by communities, technicians and institutions.

- Promoting a national and international technological information network to allow the effective exhange of experiences from diverse social, economical and ecological backgrounds.

- Concentrating on intensive use, deterioration prone sites, as well as identifying obstacles to proper practices and development.

- Establishing pilot areas of diverse ecological conditions where education, demonstration and reserch aspects are considered. These areas can also be used as training centers to help pass on experience obtained in similar areas. Watershed management, soil conservation and water harvesting are important topics to be covered.

- Promoting collaboration between scientists and technicians from all areas of study, as well as national and local planning to fight desertification.

By the year 2000, there will 6.35 billion human beings on this planet.

Each and every one of as will require food and acceptable living conditions.

However, if our natural resources continue to be squandered Earth will soon be nothing more than a lifeless desert incapable of providing for our basic needs.

The battle against nature and man himself is an uphill one; yet, all is not lost, hope of victory remains, through the joint efforts of communities and nations to save our children and millions of others from a future of misery, poverty, famine and death.

A Strategy for Reversing Desertification[1]

Champe Green[2]

The solution to the riddle of desertification has eluded mankind for at least 7,000 years, since the dawn of agriculture. However, the recent advancement of four paradigms have shed new light on ways to slow or reverse desertification. A holistic management planning model has evolved that offers scientists and tribesmen alike a tool to check desertification while improving the quality of human life.

INTRODUCTION

As we near the end of the 20th Century, we as scientists and land stewards are still fighting a problem that is as old as agriculture itself---desertification. The stakes have never before been higher in this perennial struggle, as many of the earth's natural systems are presently in danger of being pushed past critical levels of stability---at stake now is nothing less than the future habitability of the earth (Brown and Postel 1987).

Desertification: Tolba (1984a) coins the word to describe land degradation in arid areas. But overall, there is little agreement amongst authorities over the meaning of the term. Some view desertification as a linear cause and effect phenomena, being the result of certain events---i.e., climatic change, overgrazing by livestock, overcultivation, or deforestation. Others don't recognize desertification as having occurred until some indicator species has disappeared or become established. Finally, there are those who recognize the need to view desertification as a process that expresses early warning symptoms such as increased soil surface exposure and soil erosion and decreasing organic matter levels. These early warning signals mature into increased incidence of drought and flood, complete shifts of plant and animal communities, decreased land productivity (which is often masked by petrochemical infusion and/or mechanical treatments), sand dune encroachment, starvation, social unrest and war. It is this latter concept of desertification as a process that can be predicted, detected and reversed quickly that will be the focus of this paper.

[1] Paper presented at the U.S.A./Mexico symposium on strategies for classification and management of native vegetation for food production in arid zones. [Tuscon, Az., October 12-15, 1987].

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HISTORY

Agriculture had its origins some 7,000 years ago in the plains of Mesopotamia and the Valley of the Nile. The ancient (and until recently, buried) cities of Kish and Babylon, once great centers of empires in Mesopotamia, collapsed not so much from invading armies as from silt that filled their irrigation canals. Ultimately, the cities themselves were buried under desert sands. Mesopotamia was to see at least 11 empires similarly fall as a result of failure of canal irrigation systems due to siltation. These siltation-caused failures of empire after empire are suspected to be closely linked to disruption of dredging efforts by nomadic invaders from hinterland grassland and desert (Lowdermilk, 1953). One can strongly speculate that the desertification process occurring on these hinterland watersheds not only helped fill canals near the settlements with silt but prompted the grassland and desert inhabitants to invade those alluvial plains settlements in search of food. Why were the watersheds, the Achille's heel of any civilization, deteriorating, as they apparently were?

Similar events unfolded in the Holy Lands, which Moses characterized as "flowing of milk and honey", but today, sadly, a landscape gutted by erosion. In Syria and Lebanon, man-made deserts sprouted and now abound as unabated erosion continues under the poor stewardship and constant conflict between grazing and farming cultures.

Once the granary of the Roman Empire, North Africa today is covered by vast deserts; fully one-half of the grain supplies for the region are

now imported, and high food prices have led to riots and demonstrations in the streets of Morocco, Tunisia and Egypt (Brown and Postel, 1987). Why the dramatic decline? Was it simply a matter of overgrazing caused by too many stock, or was it something else we haven't yet understood? Lowdermilk (1953) discounts the climatic change theory, citing the presence of olive trees 1500 years old that survive alongside thriving young, planted trees.

Countless other desertification tragedies are written on the face of the land: from yesteryear's destruction of North China's watersheds (which continues unabated) leading to millions being swept away by "China's Sorrow", the Yellow River, to today's seemingly unstoppable desertification in Mali, Sudan, Chad, Niger, the United States, and the list goes on---Worldwide, some 15 million people are perishing from starvation each year (Capra, 1982). Some 67 million acres are deteriorating each year, adversely affecting approximately 850 million people (Tolba, 1984b). This century will go down in history as one in which more people died of starvation than in the sum total of recorded time. The problem is so great that in many countries, coping with its economic consequences has become a full time challenge (Brown and Wolf 1986).

In my home state of New Mexico, the Rio Puerco Basin, roughly an hour's drive west of Albuquerque, was referred to as the breadbasket of New Mexico at the turn of the century. Sheridan (1981) characterizes the area now as the worst eroding river basin in the west. Despite seven decades of livestock reductions, massive range reseeding, contour ridging and dam building efforts, all at tremendous cost, the Rio Puerco Basin remains unstable, with some arroyos widening by 50 feet/year. Consequently, the Rio Puerco, though supplying only 10% of the water volume to the Rio Grande, contributes over one-half of the silt load (Sheridan 1981). With abandoned villages dotting the land, one must wonder how an area that once must have been high in soil fertility and organic matter as to be called the bread basket of New Mexico could desertify so quickly. Even more puzzling is the observation that 50-year old rested exclosures look little different from adjacent land supporting livestock today (see fig. 1).

The Rio Puerco Basin is but one example of severe and apparently unstoppable desertification occurring in the U.S. Dregne (1977) estimated that 225 million acres in the U.S. have experienced severe or very severe desertification. The actual acres threatened by severe desertification are about twice that amount. These figures may be conservative if they are based on conventional range assessment techniques.

A "Catch 22" situation is drawn to light from this historical look at the nagging perennial problem of desertification. After 7,000 years, it has become apparent that we haven't understood the problem, but have only reacted to symptoms as the problem worsened. Many have taken to blaming the

Figure 1.--Fifty year old exclosure near Cabezon, NM. Note moribund remnant grasses and lack of seedling establishment. Photo by Champe Green.

worldwide population boom as the real culprit of land degradation. Yet many civilizations, such as the Anasazi at Chaco Canyon, New Mexico and other civilizations previously mentioned in this paper were not heavily populated cultures; nonetheless, their communities and agriculture collapsed. Today, New Mexico is desertifying as badly as anywhere in the world (Savory 1985b), yet there is virtually no one living out on the land; the bulk of the state's population live in four cities. These ironies point not to population as the scapegoat for land deterioration, but possibly to something much deeper.

Similarly, in analyzing the land degradation nemesis from a different perspective, Savory (1986) summarizes in Table 1 the "known" causes of environmental deterioration in Africa, and alongside has shown the antithesis of these causes as are found in the state of Texas (Texas was used as a comparison because of its predominantly private land ownership). Conclusively, one would expect to find minimal, if any desertification occurring in Texas. Tragically, as early as ten years ago, Dregne (1977) described the western half of Texas as suffering from moderate to severe desertification. In recent years as many as 200 farm or ranch families a week have left the land.

Capra (1982) cites a 1979 Washington Post story entitled "The Cupboard of Ideas Is Bare," in which prominent intellectuals admitted they were unable to solve the nation's most urgent policy problems (economic decline, crime, resource degradation, etc.). One of the "mainstream" academicians interviewed stated that he was resigning his chair because "I don't have anything to say anymore. I don't think anybody does. When a problem becomes too difficult, you lose interest."

At this point, it is perhaps appropriate to question if in fact the desertification process and its subsequent effects of poverty, starvation, economic collapse, crime and war are not all parts

AFRICA / TEXAS

AFRICA	TEXAS
• High Rural Populations	• Very Low Rural Populations
• Overstocking with Livestock	• Little or No Overstocking
• Overcutting of Trees	• Massive Brush Eradication Programs
• Bad Run of Droughts	• No Run of Droughts
• Cultivating Unsuitable Soils, Steep Slopes, Etc.	• Flat Land State
• Low General Education of Farmers	• Thousands of Graduate Farmers
• Poverty	• Extreme Wealth
• Communal Tenure of Land	• Private Tenure and Deep Love of Land
• Shifting Agriculture	• Stable Agriculture
• Insufficient Fertilizers, Herbicides, Machinery, Etc.	• Massive Availability of Chemicals and Machinery
• Poor and Somewhat Corrupt Administrations	• Large Bureaucracy, Low Level of Corruption
• Inadequate or No Extension Services	• Large University and Government Extension Services

Table 1.--Summary of "known" causes of land degradation in Africa contrasted with present conditions in Texas.

of the same problem---that problem being a heretofore lack of knowledge and understanding of four recently discovered concepts that have ultimately tied together humans, their values, goals and economics and the soil surface into a whole ecology.

REVERSING DESERTIFICATION

The human mind can only entertain two or three notions simultaneously. Our minds need some sort of aid to allow us to handle the many variables that interact in resource management. As Aldo Leopold (1949) stated in A Sand County Almanac, "The outstanding scientific discovery of the twentieth century is not television, or radio, but rather the complexity of the land organism." Add to this "complexity" the powerful concepts emerging from the field of organization development with regard to human values and social customs; further throw in the necessity in most cases of generating wealth, and it becomes apparent that what we lacked in our search for solutions was a way to look at the wider implications of various decisions before we made them--- a way to view any aspect in its relationship to the whole being managed.

The Holistic Resource Management Model

Holistic Resource Management (HRM) was developed specifically to meet this need. It rests on 30 years of rigorous testing and practice in Africa and the United States on private ranches and farms, public and tribal lands, national parks and refuges. It is applied through a planning "model" (see fig. 2) which helps one structure his thoughts in order to cater for many variables. Application begins with the establishment of a 3-part goal, without which the model becomes inoperative and holistic management compromised. To achieve this goal, a determination is made as to what level the ecosystem blocks must function. Under eight headings the HRM model incorporates all tools available to manage the ecosystem to achieve the goal. Then, it provides guidelines which force one to think through the variables that may be involved and to select the best of numerous options. Once a decision is made, there are further guidelines that help one apply the tool in the right way. Practice is always governed by a careful plan-monitor-control-replan procedure which reduces risks and prevents serious mistakes.

The HRM model can be applied in four different modes: management; policy analysis; diagnostic and research orientation.

The Goal

If the model is to be effectively used to halt desertification worldwide, in a nation, or on a farm or ranch, the three part goal must be attuned to the social structure, social processes and cultural history of the people(s) involved. A sense of having "had a hand" in the development of goals is imperative if success is to be ensured and land degradation minimized. International development and assistance programs are now influenced by the realization that perhaps the greatest contribution that can be made is facilitating the discovery by the people affected as to what they really want. Gone are the days of an expert or team of experts defining a single technological solution to agricultural production woes while remaining ignorant of or callous to the environmental and socioeconomic complexities that are likely to be present. The well intentioned Rockefeller sponsored research program that began in Mexico in 1940 and the Green Revolution to which it gave birth perhaps pointed out the problems with that approach most markedly to date (Wright 1984). Similarly, the exodus of farmers and ranchers off

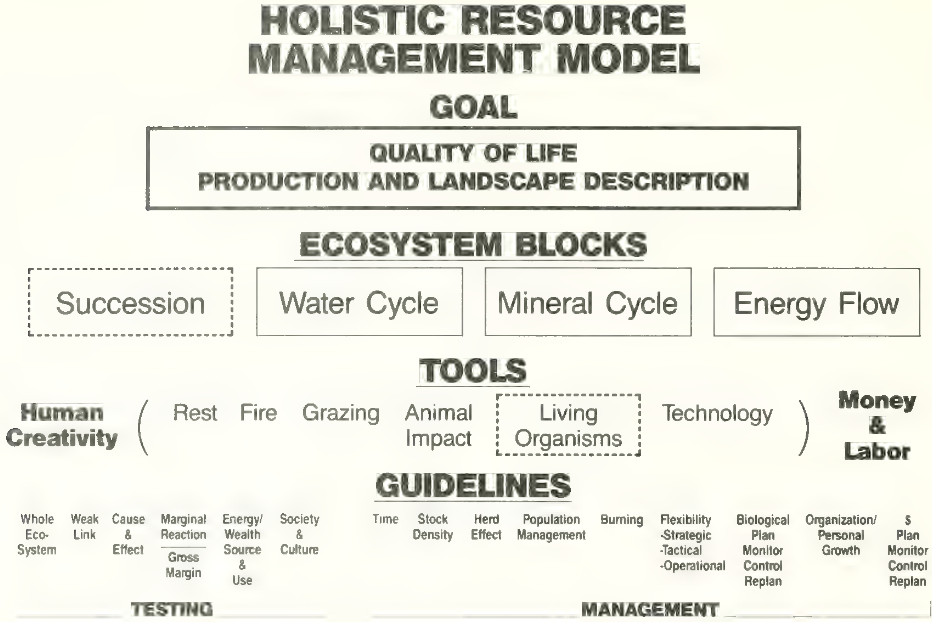

Figure 2.--The Holistic Resource Management Model.

the land in the U.S. may be due in part to the typical top-down hierarchical structure where lack of attention to and participation in goal setting is minimal, thereby hindering real commitment and creativity.

The first part of the three-part goal necessitates a definition of the quality of life desired. Wendell Berry (1979) maintains that agriculture must produce much more than crops, it must produce healthy, happy families, stable rural communities, low crime and other sociological wants and desires. The quality of life component of the goal furnishes an umbrella vision which strongly influences the remaining components of the goal.

The production part of the goal addresses what is to be produced from sunlight energy to achieve the quality of life so desired. It may be for profit, aesthetic or cultural reasons, as the case may be, but always in the broad sense of the whole and not in a narrow focus such as eliminating a problem plant or producing so much yield or so heavy a calf.

The landscape description component of the goal simply defines a futuristic vision of what the ecosystem will have to look like to sustain the production and quality of life components over time.

The Ecosystem Blocks

If the goal is to be achieved, whether it be for a state or nation, or an individual ranch, the level of functioning of the whole ecosystem will determine the degree of success. While all ecosystem processes are interrelated, for conceptualization purposes, the ecosystem is broken into four fundamental processes. The effectiveness or ineffectiveness of the water cycle and mineral cycle, the level of successional communities of plant and animal life and the level of sunlight energy captured and converted by the land are all defined seperately relative to the landscape description specified in the goal.

All ecosystem processes are functions of a very basic premise in ecology: the management of the soil surface. It is on this important concept that I would beg to differ with the the title of this symposium, "Strategies for...Management of Native Vegetation for Food Production.." I would insert "soil surface" in place of "native vegetation," for it is how mankind treats the soil surface that determines his ability to achieve his production goals for food. The collapse of empire after empire addressed earlier in this paper attests to the importance of management of the soil surface.

The Tools

Three broad categories of tools exist which can be applied to influence the ecosystem. The "land" tools of rest, fire, grazing, animal impact, living organisms and technology are applied through the vehicles of human creativity, money and labor. Under these headings fall all the tools known to man.

Rarely does any tool act solitarily on the ecosystem. Rather, two or more tools may be in operation simultaneously, exerting ripple effects indistinguishable from those of either tool in isolation. By understanding the tendencies of the tools to affect each other and the ecosystem, we can choose the appropriate combinations to achieve our goals.

The Guidelines

The guidelines of the model serve the same functions as the feedback mechanisms of an airplane. Any time one uses the tools of an airplane (ailerons, flaps, throttle, rudder, etc.) contrary to the four principles of flight, noise and visual alarms are activated. The six "testing" guidelines of the HRM model perform a similar function by warning you if your application of the tools is not the most ecological, economical and culturally acceptable path toward achievement of your goals. Similarly, the remaining "how to" or management guidelines are like the various gauges of an airplane in that they direct you back on course and assist you in properly planning, monitoring and controlling the continued flight of the aircraft. The guidelines are a rapidly developing part of the model due to the experience and knowledge gained in holistic management by scientists and land stewards worldwide.

THE MISSING KEYS

The HRM approach using a planning model is the culmination of four new discoveries made over the past 60 years. Much controversy has surrounded HRM, as virtually every one of the four discoveries has gone against an existing belief system. Historically, the path of a new idea runs the gamut from persecution and ridicule, through controversy, to universal acceptance (Boorstin, 1983). Witness Galileo's house arrest for years as punishment for validating Copernicus' work that the Earth was not the center of the Universe, but orbited around a minor star in but one solar system. Today, belief that the Earth is the center of the Universe would be greeted with belittlement.

Three of the missing keys deal directly with the desertification of the world's watersheds in arid and semi-arid lands (encompassing an estimated 75% of the terrestrial surface of the earth). The fourth concept, holism, made the development of a management model imperative to ensure sound resource management (Savory 1985a).

Holism

Dating from Descartes and Newton, some 300 years ago, the scientific approach became fragmentary and reductionist, espousing the belief that all aspects of a complex phenomena could be understood by reducing them to their component parts (Capra 1982). This reductionist approach has resulted in some spectacular advances in such areas as transportation, communications, medical technology, defense systems, etc. However, in the total management of natural resources which involves human values and more, the approach has failed miserably, resulting in massive starvation, land deterioration, exhaustion of fossil fuels, social unrest and conflict (Savory 1987).

From the basic divisions of earthly things into life, matter and mind came thousands of disciplines. Under the reductionist approach, each discipline developed its own jargon, professional societies, professional jealousies and an increasingly narrow focus in an effort to better understand the whole. Ultimately, this type of thinking has led to statements such as one heard by this author from a prominent agronomist at a major midwestern land-grant university, that "the only connection between any of the departments at my university is the plumbing system." The logical next steps beyond reductionism have been multidisciplinary and interdisciplinary approaches. However, experience is showing that, however well intentioned, this combination of reductionist viewpoints remains reductionist.

Jan Smuts, general, scholar and a founder of The League Of Nations first advanced the concept of holism in 1926 in his book Holism and Evolution. Smuts' concept of holism suggested that there are no parts in Nature, only wholes and interrelationships. Any sustainable success by man in managing the ecosystem will depend on his ability to understand these interrelationships.

Upon gaining insight from Smuts' work on the need to apply holism in management, it became necessary to develop a simple and practical "thought" model---which today stands as the Holistic Resource Management model. This enables a manager to manage resources from a holistic (rather than reductionist) point of view.

Brittle and Non-Brittle Environments

Typically, terrestrial environments have been classified as savannah, prairie, desert, tundra, grassland, temperate and tropical forest, etc. These biome classifications have been based on predominant vegetation types occurring due to rainfall amount and edaphic factors.

Savory (1985b) has shown that there are two broad types of environment that have little to do with rainfall amount, but instead are characterized by reliability and regularity of precipitation, as well as speed of decay process (see Table 2 for complete criteria). There are no absolutes on the continuum between brittle and non-brittle environments, only tendencies. An environment tends toward brittleness, for example, if the decay process is slow, mechanical (weathering) and oxidative. Brittle environments are very susceptible to desertification processes, while environments tending toward non-brittleness are more resilient to prolonged periods of abuse and misuse.

The concept of brittle and non-brittle environments is crucial to understanding desertification and thus, its remedy. If the nature of brittle environments is not understood, then man's ignorance accelerates desertification as we try to remedy it; our solutions become part of the problem (Savory 1985b).

NON-BRITTLE vs. BRITTLE ENVIRONMENT

Using a Scale of 1-10

1		10
NON-BRITTLE RELIABLE, HIGH OR LOW	**RAINFALL**	BRITTLE UNRELIABLE, HIGH OR LOW
GOOD DISTRIBUTION	**ANNUAL ATMOSPHERIC MOISTURE**	POOR DISTRIBUTION
BIOLOGICAL / FAST BOTTOM UP	**DECAY**	CHEMICAL / PHYSICAL / SLOW TOP DOWN
EASY, FAST START ON SMOOTH SURFACES	**SUCCESSION**	HARD, SLOW START ON SMOOTH SURFACES
COMPLEXITY AND STABILITY	**REST (NON-DISTURBANCE)**	SIMPLICITY AND INSTABILITY
TIGHT GROUND COVER	**OVERGRAZING PLANTS**	BARE GROUND
	GRASS PLANT SPACING	

Table 2.--Differences between brittle and nonbrittle environments.

The term "fragile" enviroment should not be confused with the concept of brittleness, as there can exist fragile environments that are tending toward either brittleness or non-brittleness.

Role of Herding Ungulates and Predators in An Environment Tending Toward Brittleness

In considering whole communities and interrelationships of plants, animals and soils in brittle environments, a question we might ask ourselves is this: "what influence could have removed old plant material from perennial grasses, broken soil interplant surfaces and provided the degree of compaction necessary for seedling establishment over millions of acres for millions of years, routinely?"

Herding ungulates and their predators are strongly correlated with brittle environments (Savory 1985b). Vast herds of bison, antelope, deer and elk and their predators roamed much of western North America, whereas these populations were much less substantial and their behavior quite different in the more non-brittle areas of eastern North America. Too, in Africa and on other continents, herding ungulates and predators have evolved immensely complex interrelationships (Dasmann 1964).

The link between brittle environments and the behavioral-related disturbance provided by herding ungulate populations is essential in understanding the process of desertification (Gadzia 1986). Trampling of old, standing oxidizing plant material onto the soil surface sets off a chain reaction of events: the moribund plant is freshened from obtrusive old growth; the soil surface is protected from raindrop impact and extremes in surface temperature; moisture retention and aeration are ameliorated, and adequate compaction offsets freezing and thawing actions, thereby setting the stage for seedling establishment.

Unfortunately, the calm movements of livestock in pastures or being tranquilly herded by pastoralists do not have the same effects on plant and soil communities that migrating wildlife ungulates or wildlife bunching protectively from predators did. However, domestic livestock can be induced to exhibit an excited behavior with the use of attractants, or when a predator does occassionally inspire the herd.

Role of Time in Community

Andre Voisin, a French scientist, showed with his research that overgrazing of plants was caused by the length of time the plant is exposed to the grazing animal, not by numbers present (Voisin 1961). Yet tragically, the belief that overgrazing could be controlled by reducing animal numbers has been a cornerstone of range management worldwide. By reducing numbers and scattering animals thinly across the land to prevent overgrazing, plants are still continually being overgrazed,(the time dimension is still being ignored) though fewer plants are overgrazed because there are fewer animals to do it. Simultaneously, fewer animals mean there is less impact on the soil surface, less litter deposited, and less crusted surface area broken to both increase aeration and provide for seedling establishment. Evidence the moderate to severe desertification occurring in West Texas (Dregne 1977) as previously mentioned, despite a decline in stocking rates of 1.5 animal units per

section per year since 1900, as recorded by the Sonora Experiment Station (Bentley 1902; Merrill 1959; Steger 1987). This disastrous combination of effects begins to account for how we managed to cause more damage to our brittle environment rangelands in a century than nomadic people had done in a few millenia (Savory 1985a).

There are countless instances now evident of successful control of the time element in minimizing overgrazing and overtrampling. This can easily be accomplished by fencing, herding, etc. and monitoring of growth rates of plants to regulate timing of moves. What is still a challenge facing those of us as scientists and stewards is how to minimize overgrazing and overbrowsing by wildlife whose migratory routes and ranges have often been blocked or have dwindled, and whose predators have been removed.

CONCLUSION

With the recognition of these four "missing keys" and their culmination into a practical method for managing holistically, we now have the capability to arrest the 7,000 year trend toward increasing desertification. But there is no one set strategy---there are many. The "how to's" are spawned by human creativity and tested and applied through the use of the HRM model. The two sacrosanct axioms to ensure success are: 1) sociological considerations must be a part of any solution to halt desertification and that is best accomplished by the affected people developing their own goals, and 2) the necessity of planning, monitoring, controlling and replanning, if necessary, to achieve those specified goals. By adhering to this common sense approach, which is the very foundation of the HRM model, we are capable of predicting with a high degree of certainty whether policies will further exacerbate the encroachment of deserts. Using the model in its diagnostic mode enables us to detect early on any advancement of the desertification process, and similarly, in the management mode we can quickly reverse that process.

The Center for Holistic Resource Management, a non-profit membership and educational organization located in Albuquerque, New Mexico, was formed in 1984 by a group of resource managers, researchers, farmers, ranchers and environmentalists to provide training and dissemination of knowledge on HRM. Working in an international collaborative effort, the Center now acts as a focal point for the rapid increase in knowledge that is taking place through practical application of the HRM model.

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Reversal of Desertification on the Low-Shrub Cold Desert[1]

Warren P. Clary and Ralph C. Holmgren[2]

Abstract.--The low-shrub cold desert has been used as livestock winter range since the late 19th century. Severe deterioration resulted from earlier, improper grazing practices. Data and observations in the 1970's and 1980's suggest a reversal of desertification has occurred under improved grazing practices.

INTRODUCTION

The rangeland we call the low-shrub cold desert is a plant association or formation also known as the Northern Desert Shrub, the Salt Desert Shrub, the Shadscale Zone, and the Greasewood-Saltbush Association (fig. 1). Our experience and observations have all been in the Great Basin part of its geographic range. It is possible that other results have occurred in the geologically different Colorado Plateau.

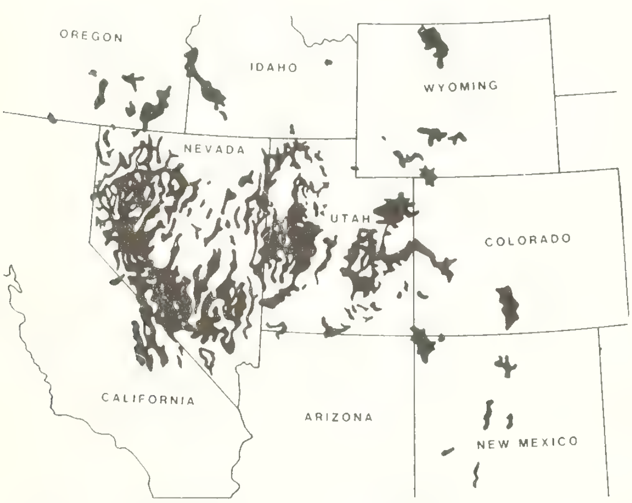

Figure 1.--Distribution of low-shrub cold desert (from Blaisdell and Holmgren 1984).

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This arid range is dominated by low shrubs (ca 25 cm), often with grasses as associates. These occur as a mosaic of plant communities largely dominated by shrubs and half-shrubs of the family Chenopodiaceae. Some of the most important species are shadscale (Atriplex confertifolia), Gardner saltbush (A. gardneri), mat saltbush (A. corrugata), fourwing saltbush (A. canescens), Castle Valley clover (A. cuneata), winterfat (Ceratoides lanata), and spiny hopsage (Grayia spinosa). Several shrubs of the family Compositae are also prominent members of these communities including bud sagebrush (Artemisia spinescens), black sagebrush (A. nova), and low rabbitbrush (Chrysothamnus viscidiflorus ssp. stenophyllus). Associated grasses include Indian ricegrass (Oryzopsis hymenoides), squirreltail (Sitanion hystrix), Sandberg bluegrass (Poa sandbergii), galleta (Hilaria jamesii), alkali sacaton (Sporobolus airoides), sand dropseed (S. cryptandrus), and blue grama (Bouteloua gracilis) (Blaisdell and Holmgren 1984).

In pristine condition, plant production was, we think, almost wholly from woody and herbaceous perennials. Annuals were most likely a negligible constituent. Generally, vascular plants cover less than 10 percent of the ground. Production of plant material above ground averages about 280 kg/ha annually.

Climatically, the country is a cold desert: cold winters, warm summers. At the Desert Experimental Range near the center of the distribution of the low-shrub cold desert, the temperatures have varied from -40 °C to +40 °C over a 50-year period, while the average annual precipitation was 157 mm.

EARLY USE

The low-shrub cold desert was one of the last range types to be exploited through livestock grazing (final decades of the 19th century), and the land still remains almost

entirely in public ownership. The first half-century of use saw unregulated grazing over this desert. Use was such that deterioration was well under way after only about 30 years of such treatment (Griffiths 1902).

The decline continued into the middle of the 20th century, typically with livestock grazing given as the cause (Barnes 1926, Campbell et al. 1944, McArdle et al. 1936, Stewart et al. 1940, Robertson and Kennedy 1954, Wooton 1932). The term desertification was not yet in vogue, but strong words and vivid phrases described what was happening: depletion, land misuse, deterioration, grazing damage, injury by grazing, and the evils of unregulated range use. In many areas substantial soil losses occurred as a result of vegetation cover denudation and loss of protection from wind. "The stifling clouds of dust that race over the desert valleys are fed from areas largely denuded of vegetation" (Stewart et al. 1940). Pedestaled plants illustrated up to 15 cm of soil loss. Deteriorated areas were often covered with embryonic dunes. In the most extreme cases "blow-out" holes up to 4 m deep and 2.5 ha in extent were formed (Bailey and Connaughton 1936). Deterioration in the early part of this century was such that people asked, "Is Utah Sahara bound?" (Cottom 1947).

It was not only the specialists--botanists, agrostologists, agronomists--who could see the decline in productivity and foresee the economic consequences. Users, too, recognized what was happening, and some of these declared the cause to be improper grazing use. Other users theorized a changing climate to be the cause, but that idea was convincingly put to rest by Stewart et al. (1940).

GOVERNMENT POLICY AND PRACTICE

Federal Government natural resource policies played a significant role in the desertification process of Western United States rangelands. Such policies encouraged fragmented ownership patterns that made proper grazing management difficult and allowed unrestricted common grazing on public lands. Improper use of the land was virtually assured when these policies were added to the early settler's lack of knowledge about arid lands and their pioneer philosophy that natural resources were nearly inexhaustible (USDA Forest Service 1936).

Finally, Congress, stirred by the needs of livestock operators as well as by the alarming reports and observations of conservationists and the agricultural specialists, responded to public demand for action and passed the Taylor Grazing Act of 1934 creating an agency of the Federal Government to manage these public lands. Over the years steps were taken to acquire control and to implement use practices thought to favor conservation of the range. Slowly and steadily the Division of Grazing (now the Bureau of Land Management) implemented measures to mitigate the damaging grazing pressure--slowly in order to avoid sudden economic calamity for individuals and small communities, and slowly also to avert political reaction.

Over several years, the new agency first got compliance with two major declarations of eligibility of livestock herds for use of these grazing lands: proof of prior use of specific areas during a period of years before the enactment; and "commensurate property," privately owned property within some reasonable distance that together with the public land could constitute a year-around ranching operation. This earliest regulation reduced the pressure of animal numbers. Later, specific areas were allotted to individual operators or associations of smaller units. This action not only reduced strife but encouraged proprietary interest in condition of the assigned lands, another positive measure.

Still later the allotments were surveyed for productivity, and allowed animal-days per year were further adjusted to better conform with carrying capacity--almost always a downward adjustment. Finally, and a still continuing program, the allotments were subjected to more intensive management, with the institution of grazing systems planned to get improved distribution of animal use over the allotted range units, and to lessen continual same-season use through some rotational time of occupancy of specific parts of allotments.

ACCUMULATION OF KNOWLEDGE AND EVIDENCE OF CHANGE

Since the time of initial concern, researchers have developed considerable information on grazing ecology of the low-shrub cold desert. Hutchings and Stewart (1953) studied influences of grazing intensity, plant preferences, community subtypes, and precipitation on plant community response to grazing. Later, Holmgren and Hutchings (1972) found season of grazing of great importance, and it became apparent that successional trends differed in different areas as grazing pressure increased or decreased.

Further studies documented a reversal of the early century desertification (Harper 1959, Holmgren and Hutchings 1972, Hutchings 1954, Hutchings and Stewart 1953, Norton 1978). Although evidence shows current levels of livestock use are still significantly affecting plant communities (Clary 1986, Clary and Holmgren 1987), there appears to be little controversy that improvements in condition of the desert have occurred. Somewhat less agreement exists as to the cause of the improvements in different situations. Difficulties arise in interpreting causative factors of change (Clary and Holmgren 1987, Sharp and Sanders 1978, West 1982).

Many of the vegetation successional trends in the low-shrub cold desert are somewhat unexpected, related perhaps to complex environmental interactions. However, in terms of what humans can control, evidence dating back 50 years has demonstrated in various ways (1) that livestock grazing can severely deplete this cold desert vegetation, (2) that removal of livestock grazing results in recovery of the vegetation community, and (3) that continued livestock grazing, under improved management, can also result in recovery of the vegetation community, but at a slower rate and perhaps by a somewhat different successional route (Clary and Holmgren 1987, Holmgren and Hutchings 1972). Manipulation of grazing season and intensity on experimental units has resulted in improvements of forage plant production (Smith 1986), relative plant cover composition (Clary and Holmgren 1987), and total plant cover (Blaisdell and Holmgren 1984).

Cryptogamic soil crusts are important to soil stability and are affected by grazing management. Typical desert crusts of nonvascular plants (primarily lichens, mosses, and algae) reduce detachment of soil particles by wind and rain and increase water infiltration (Anderson et al. 1982a, 1982b, Johansen and St. Clair 1986). Hoof action by grazing animals greatly impacts the protective crytogamic crusts, particularly in the hot dry summer when the brittle crusts have little chance to recover (Anderson et al. 1982b). Thus, reducing or eliminating livestock use during the spring and summer can increase soil stability through improved cover of both vascular and nonvascular plants.

Evidence shows that improvements in livestock management have allowed a reversal of the earlier desertification process on public lands as well as on experimental areas. This evidence is in a number of forms. For instance, the descriptive evidence of decline of range condition (incipient desertification), so common in the first half of the 20th century, is no longer the alarum cry that it was. Desert dust, the duning, the blowouts are no longer common phenomena.

In our observation, ranges once judged to be in poor condition may still be like that, but the indicators of downward trend in condition are not so obvious now. Areas without perennials as a result of past abuse have stabilized with annual weed cover following the reduction of grazing pressure (fig. 2). But where there was a remnant of perennial species desirable for forage, there has been on some range areas more positive results than attainment of land stability. There are signs of change in floral composition to what we presume (on evidence of exclosures) to be in the direction of the pristine.

Early concerns about grazing impacts on winter grazing land had led to the installation of a series of study plots in western Utah and

Figure 2.--Improvement in soil stability in Wah Wah Valley, Utah, from (A) 1935 to (B) 1982 (from Blaisdell and Holmgren 1984).

across central and northern Nevada. This series of 1.6-ha plots was established in 1932 through 1939, or approximately at the time grazing on public lands came under some control, and reread in 1981 and 1982. Although the plots were subjected to continued grazing for up to 50 years after the initial plot reading, they demonstrated significant increases in cover of perennial grasses and palatable shrubs (table 1). We find that perennial grasses (mainly Indian ricegrass, galleta, and squirreltail) and

Table 1.--Change in cover of grazed plots on the Bureau of Land Management low-shrub cold desert from the 1930's to the 1980's.

Plant group	1930's	1980's	Significance
Grasses	0.50	1.50	P<0.01
Palatable shrubs	3.02	3.38	P<0.10
Unpalatable shrubs	2.04	1.70	NS
Total cover	6.29	7.11	NS

and palatable shrubs (mainly winterfat, black sagebrush, and bud sagebrush) as a group have significantly ($P<0.01$) increased in the proportion of the total plant composition in these desert valleys. These plants are preferred by grazing livestock, and at least some of them tend to dominate in the long-term absence of grazing. Increases in the proportion of such plants are considered strong evidence of the recovery of a plant community from earlier grazing excesses.

CONCLUSIONS

Desertification may seem to some to be an almost inevitable consequence of livestock grazing in arid and semi-arid regions. However, evidence has been presented in international forums that improvements under managed use have been occurring in different countries (Box 1986). Our experience has shown that the low-shrub cold desert of the Intermountain West is surprisingly dynamic and responds to changes in grazing pressure, weather, and other factors.

A significant reversal of the earlier desertification of much of this cold desert has been attained even though livestock grazing continued. Observed improvements in plant and soil condition have resulted from a combination of long-term change in Federal land management policies, and because scientists and land managers developed a greater understanding of the ecosystem limitations and applied grazing management in a manner to stay within those limitations. Management changes such as reductions in livestock numbers, limitations on spring and summer grazing in some areas, and the application of some rotation of deferment or rest have improved conditions on much of the Great Basin low-shrub cold desert.

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How Desertification Affects Nitrogen Limitation of Primary Production on Chihuahuan Desert Watersheds[1]

Walter G. Whitford, James F. Reynolds, and Gary L. Cunningham[2]

It is hypothesized that the shift from perennial clump grasses to shrub dominated ecosystems in the Chihuahuan Desert has resulted in a change from predominantly water limited ecosystems to nitrogen-water limited ecosystems. In shrublands nitrogen and water are concentrated in patches under individual shrubs. This patchiness affects the temporal linkage between water inputs and nitrogen availability. Nitrogen and water availablility are also affected by redistribution of organic matter by wind, water and animals. Shifts from grassland to shrubland results in increased temporal and spatial variability of these essential resources for plant production. Models for predicting primary productivity on desert landscapes must include linkage between mechanistic nitrogen models and broad spatial scale organic matter transport and accumulation models.

In a review of definitions of desertification Verstraetae (1986) emphasized the United Nations definition, "The diminution or destruction of the biological potential of the land...the widespread deterioration of ecosystems under the combined pressure of adverse and fluctuating climate and excessive exploitation." Verstraetae (1986) goes on to point out that desertification is not drought, soil erosion, destruction of the vegetative cover, cutting of trees nor even the degradation of living conditions alone, but it is all of that and much more. It is the "much more" aspect of desertification that we emphasize here. In this paper we examine how desertification has affected nitrogen limitation of primary production in the Chihuahuan Desert of North America. We develop the hypothesis that the deterioration of Chihuahuan Desert ecosystems has not necessarily resulted in reduction in primary production, but has affected the temporal linkage between rainfall and production and has affected spatial patterns of water and organic matter redistribution.. The "deterioration" assessment in Chihuahuan Desert ecosystems is based on loss or reduction in palatable forage species for domestic livestock. Palatable vegetation has been replaced by unpalatable or low forage-quality species. We suggest that reversing desertification or improving the yield of usable (directly or indirectly to humans) biomass requires sufficient understanding of the Chihuahuan Desert ecosystem processes and landscape relationships to allow an opportunistic strategy of land management (Westoby et al. 1987). In this paper we address factors affecting nitrogen availability and the linkage between organic matter transport and redistribution and available soil

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nitrogen. In addition we present a discussion of modelling strategies applicable to these problems.

The large scale changes in vegetation in the Chihuahuan Desert during the past century is well documented (Branscomb, 1956; Gardner, 1951; Buffington and Herbel, 1965; Ares, 1974; Wright, 1982). Most of the areas that were characterized as relatively uniform stands of perennial grasses in the 1880's now have little or no cover by these grass species and are now shrub desert habitats. The remnant perennial grasslands occur as small patches, swales of relatively low forage quality species like tabosa, Hilaria mutica or as short life span clump grasses (e.g. Sporobolus spp.) and low shrub (Xanthacephalum spp.) associations. While there have been periods defined as climatic "droughts" during the past century, these periods did not result in the complete disappearance of perennial grasslands but did result in marked reduction of that habitat (Conley et al., 1987) undoubtedly as a result of climate interacting with overgrazing. Obviously both shrubland and perennial grassland can be maintained under the current climate. If both shrublands and grasslands are self-sustaining in the current climatic regime, what are the inherent differences in these systems that allow this?

The conventional view of arid ecosystems is that system processes are driven by water which is available in irregular pulses (Noy-Meir, 1973). Almost by definition, such ecosystems have been viewed as water limited systems. The use of "limited" in the context of deserts conveys the idea that processes such as primary production, decomposition, populations dynamics, etc. will increase in proportion to the quantity of water input to the system. However we now know that such is not the case (Whitford, et al. 1986, Fisher et al. 1987, Schaefer et al. 1985, Gutierrez and Whitford, 1987a). An additional factor that appears to limit some of these processes is nitrogen availability (Ettershank et al. 1978, Gutierrez and Whitford 1987b, Gutierrez et al. (1987), Lightfoot and Whitford (1987).

The heterogeneity of desert watersheds or landscapes should thus be viewed in the context of both nitrogen and water limitation. Both total nitrogen and nitrogen mineralization potential vary on a desert landscape and this variation appears to be related to topographic position, soil organic matter and soil texture. Within the more homogeneous subunits or patches there is considerable variation in soil nitrogen and soil organic matter. Within a larger landscape subunit many of the "hot spots" or patches of higher organic matter, higher soil nitrogen and elevated soil water have their origins in the soil moving and nest building activities of vertebrates and arthropods, plus, the loss or deposition of materials by aeolian and fluvial forces.

A conceptual landscape model of an ecosystem is shown in Figure 1. Two submodels, a "point" model and a "transport" model are depicted. In Chihuahuan desert ecosystems, the key processes are the interactions between water availability and nitrogen availability. These processes are described later in the text and are the subject of simulation modelling efforts. The models of processes do not consider transport into or out of patches nor the activities of animals that change water and organic matter status of soil within the patch. The landscape level processes that affect the availability of water and nitrogen are erosion and deposition, wind transport of fragments of plants, feces, soil etc. and transport of organic matter by central place foraging animals that concentrate organic matter in nests and burrows. In order to understand the relationships between patch processes it will be necessary to link process models with models of landscape transport processes (Fig. 1).

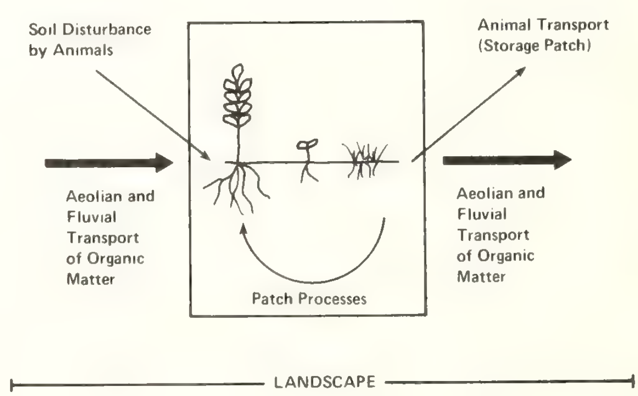

Figure 1.--The relationships between point or process models (enclosed in the box) and transport and storage processes that occur on larger spatial scales, e.g. watersheds.

The point model is intended to represent ecosystem dynamics at a specific location or patch in the landscape. No explicit consideration is given to external imports of carbon and nitrogen

SITE CHARACTERISTICS	GRAMA I	UPPER II	LARREA III	BASIN SLOPE IV	V	VII	PLAYA FRINGE III	PLAYA IX	BASIN GRASS	MESQUITE DUNES	HILARIA SWALE	BASIN GRASS SHRUB
1. Tight Rhizosphere N cycle	+++	-	-	-	-	-	-	++	+++	-	+++	+
2. Dense root mat	+++	-	-	-	-	-	-	+++	+++	-	+++	+
3. Soil Microbial Biomass	+++	-	+	-	-	+	++++	++++	+	+++	++	+
4. Denitrifier biomass	-	-	-	-	-	-	++	+++	+	++	+++	-
5. Nonmicrobial soil organic matter	+	-	+	-	-	+	+++	+++	+	+++	++	+
6. Nonsymbiotic N Fixers	+++	+	-	-	+	+	+++	+++	+++	-	+++	++
7. Rhizobium nodulated herbaceous legumes	++	++	+	+	+	+++	-	-	-	-	-	-
8. Rhizobium nodulated or actinorhizyal shrubs	+	-	-	-	-	+	+++	-	-	++	-	+
9. Cyanobacteria/lichen crusts	-	-	+	-	-	-	-	-	-	-	++	+
10. Termites	-	++	++	+++	+++	+++	-	-	++	+	-	++
11. Vegetation matrix impedes sediment loss	+++	-	+	-	-	-	+++	+++	+	-	+++	+
12. Large quantities easily moveable O.M.	+	+	++	+++	+++	+++	-	-	+	++	+	+
13. High infiltration rates	+++	+	+	+++	++++	++++	++++	-	+++	+++	-	++
14. High sediment yield	-	++	++	+++	+++	+++	-	-	-	+	-	+
15. Consumer transported O.M.	+	+	++	++	+	+	++	+++	++	-	-	++
16. Architectural heterogeniety	-	-	+++	++	++	++	++	-	-	-	-	++

Table 1. Hypothesized spatial relationships of characteristics of subunit on a Chihuahuan Desert landscape that affect water and nitrogen availability of that sub-unit and adjacent sub-units. Most of the site characteristics affect hypothesized transports across boundaries of the sub-units or within sub-units. All of these characteristics affect nitrogen availability at any given point on the landscape.

(originating elsewhere in the landscape) nor of transport losses of carbon and nitrogen from that location. Carbon and nitrogen losses accounted for in the point model are ammonia volatilization, denitrification and respiratory carbon (Moorhead et al. 1986).

The relationship of point or patch processes to landscape or transport processes are suggested in Table 1. Examples of point or patch processes are: primary production, decomposition, nutrient mineralization, trophic relationships of soil biota and herbivory. This conceptualization suggests the hypothesis that transport of organic matter at the scale of the landscape has greater impact on nitrogen based processes than point processes (i.e. on the scale of soil unit to plant). Transport processes produce areas where organic matter is concentrated with relatively barren areas in between. The organic matter patches may be relatively dense as in a bunchgrass grassland area, moderately dispersed as in a shrub zone, or widely scattered as in a zone with scattered sub-shrubs and herbaceous plants.

The temporal and spatial scales at which various soil disturbances and rain events operate are summarized in Figure 2. Small soil disturbances occupy small space, occur at high frequency and may serve as repositories for wind and water bourne debris. The influence of such soil disturbances is to generate short-lived water and nutrient rich patches of small size. These do not "store" organic matter or nutrients. Soil disturbance by animals such as pocket gophers and badgers may persist for several years but are not maintained nor modified by import of organic matter or subsequent digging. Soil disturbances such as large ant mounds and banner-tailed kangaroo rat mounds are persistent features of the landscape, are continuously modified by import of organic materials and excavating activities of nest and burrow occupants. These persistent features represent "storage" patches that are nitrogen and other nutrient rich sites that have different water infiltration and storage properties than surrounding soils (Mun and Whitford, 1987).

M, N, O and P on Figure 3 are diagrammed to represent probability of return times of rain events of different magnitudes. Small events occur relatively frequently: return time < 1 year. These events affect nitrogen processes at the "point" model level. Intermediate 6mm-25cm size events usually occur yearly.

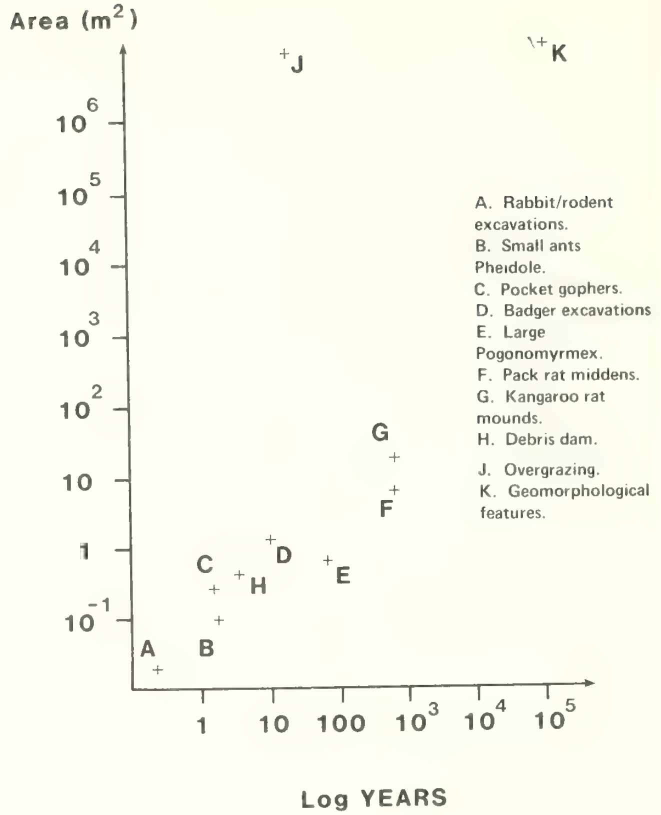

Figure 2.--Temporal and spatial scales of soil disturbance and/or organic matter storage processes.

Events of this size may produce erosional transport between landscape units or redistribution and concentration of organic materials within a unit. Events > 25 mm may initiate sheet flow. Sheet flow may be of sufficient duration and intensity to sweep transportable organic debris to the bottom of a watershed. Large events may scour sloping landscapes. These are low frequency events having probable return times of 10 years or more.

Soil movement by animals not only produces variable size patches that may accumulate organic matter and nitrogen but also produces easily dislodgeable material that is readily transported by wind and water. For example, termites build galleries around dead stems, leaves, and dung. The gallery material contains a large clay silt fraction and is nitrogen enriched (Whitford et al. 1982). This friable material is readily broken up by rain drops and by wind and transported by surface flow or wind. Using the values for gallery carton and size of the watershed, we calculated that if the

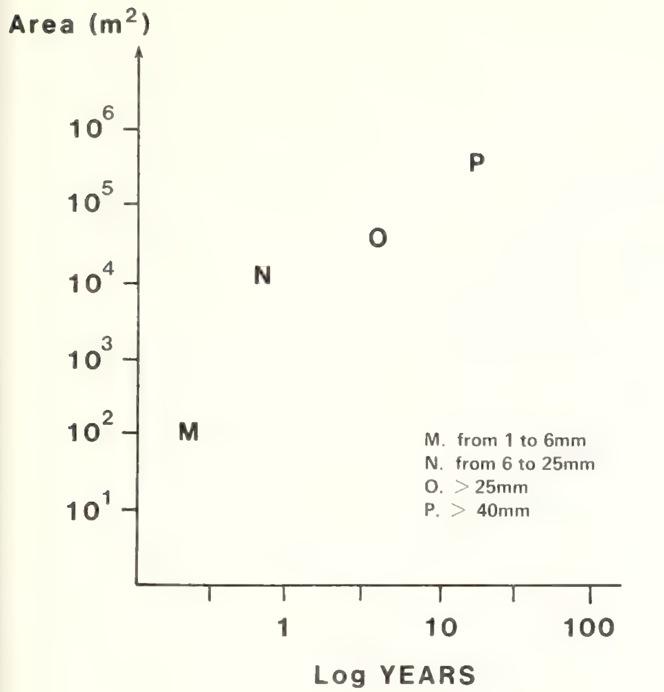

Figure 3.--Aerial extent and probable return times for single high intensity rain events in the Chihuahuan Desert.

clay-silt fraction of termite galleries were transported to the playa, they would account for 10 cm of sediment being added to the playa surface in 100 years. Add to this the fine textured soils moved to the surface by ants, rodent and rabbit diggings and this potential addition to the readily transported sediment is not to be dismissed as a factor affecting vegetation zonation and general soil properties.

The linkage between water inputs and nitrogen availability affects both the spatial and temporal variation in primary production. Understanding the water input-nitrogen availability linkage is thus essential for understanding temporal and spatial variation in primary production. The linkage between rainfall and nitrogen availability is not necessarily the same in the various units that make up a Chihuahuan Desert landscape. That linkage within a unit may be affected by inputs from and outputs to adjacent landscape units. Therefore if we are to understand the consequences of shifting from perennial grassland to shrubland, it is necessary to compare the water-nitrogen availability linkage in these systems.

There are numerous points in the nitrogen cycle where water affects the rate of transformation (Fig. 4). Some of these transformations are the subject of recently initiated research. For example, denitrification should vary as a function of nitrate concentration in anaerobic microsites in the soil. Soil water content affects the number and size of such microsites. Studies of denitrification are currently being conducted as part of the Jornada Long Term Ecological Research Program (LTER)

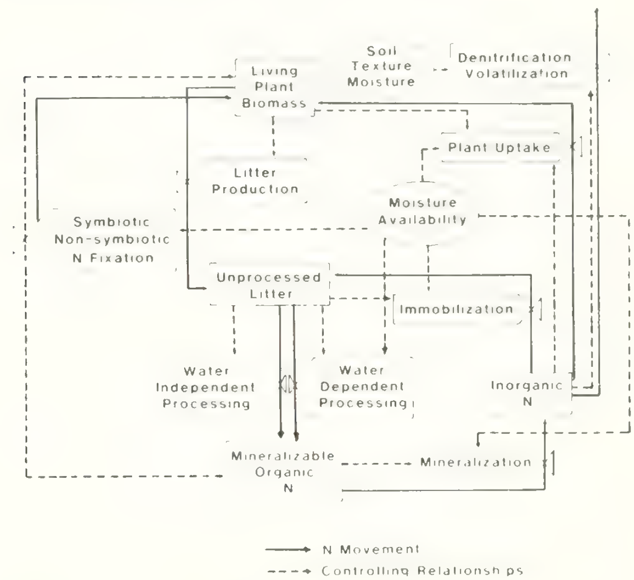

Figure 4.--Linkages between moisture inputs (availability) and nitrogen cycling processes in the northern Chihuahuan Desert.

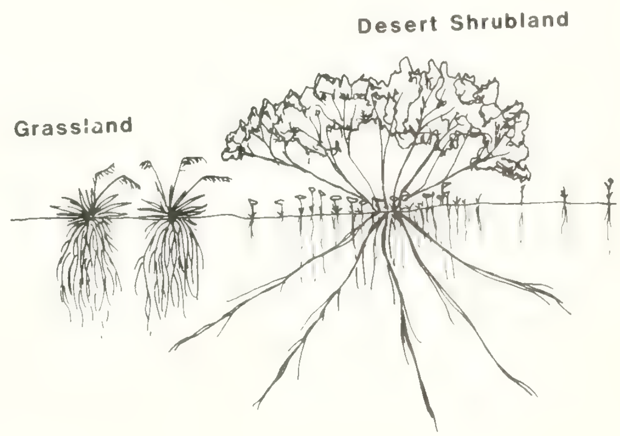

Figure 5.--Relative root mass distributions of perennial clump grasses and shrubs with annual plants under the canopy.

A source of nitrogen that is variable in space and time is nitrogen fixed by Rhizobium spp. in nodules on the roots of annual legumes. Rhizobium nodules are abundant on the roots of several herbaceous legumes that occur in some habitats on the Jornada Experimental Range: Astragalus spp. Lotus neomexicanus and Lupinus (W.G.W. pers. obs.) Moroka et al. 1982, examined the vegetation in three basin grassland sites on the Jornada, but did not report cover of any of these species. Pieper et al. (1983) did not mention annual legumes in the basin grassland despite reporting biomass of annuals accounting for less than 1% of the total peak standing crop e.g. 5-7 $g \cdot m^{-2}$. It is therefore unlikely that N inputs via fixation by symbiotic N fixing Rhizobium spp. on herbaceous legumes is of importance in the basin grasslands. On the watershed intensively studied by the Jornada LTER group, the potential input of N by N fixing annual legumes was greatest at the base of the basin slope, and high in the black grama grassland (Table 2). Ludwig et al. (1987) and Gutierrez and Whitford (1987b) reported that Astragalus spp. increased in density and biomass on irrigated plots in comparison to non-irrigated and irrigated N fertilized plots. The toe slope grama grassland and lower basin slope are the portions of the watershed with the best water storage and infiltration (Bach et al. 1986) and consistently highest soil water contents (Wierenga et al. 1987).

Table 2. Mean cover values (%) of nodulated herbaceous legumes at various positions on a Chihuahuan Desert watershed (see Figure 1) for relative positions of vegetation zones.

	Sum	Ast nut	Ast woo	Ast tep	Lot neo	Lup con
Playa	0.6	0.62	0	0	0	0
Lower Basin Slope	4.7	4.3	.3	.1	0	0
Mid-Basin Slope	0.7	.05	.6	.05	0	0
Upper Basin Slope	0.2	0.1	.07	0	0	0
Larrea Bajada	0.1	0.1	0	0	.05	0
Piedmont Bajada	2.4	0	0	0	1.7	0.7
Piedmont Grassland	0.6	0	0	0	0.4	.2

Ast nut = Astragalus nuttalianus
Ast tep = Astragalus tephrodes
Ast woo = Astragalus wooteni
Lot neo - Lotus neomexicanus
Lup con - Lupinus concinnus

Jornada LTER data: courtesy Steve Wondzell

Shrub dominated desert areas are characterized by "islands of fertility" where nutrients are concentrated in the surface soils under shrub canopies surrounded by soils of low nutrient content (Garcia-Moya and McKell 1970, Parker et al. 1982). These insular patches are not only of soil nutrients but also of soil organic matter and annual plants (Table 3). Shrub canopies and associated litter layer also result in increased soil water contents by increasing infiltration rates (Elkins et al. 1986), and by channeling water by stem flow (unpublished data - W.G. Whitford and J. Anderson). Intershrub soils have lower infiltration and generate run-off and erosion more rapidly than soils under canopies.

Table 3. Mean ± standard deviation total nitrogen content, density and biomass of annual plants under shrub canopies and in intershrub areas on a Larrea tridentata dominated site in the northern Chihuahuan Desert. Data from Parker et al. (1982).

	Canopy	Intershrub
Total N $g.kg^{-1}$ soil	40.4 ± 3.9	33.5 ± 1.9
No. Annual plants $\cdot m^{-2}$	80 ± 23	16 ± 11
G. Annual plants $\cdot m^{-2}$	24 ± 10	4 ± 1

In areas dominated by shrubs without symbiotic N fixers, available nitrogen is a function of N mineralization from decomposing organic matter. In general decomposition rates are high for leaf litter of dominant North American shrubs. P. glandulosa which had the lowest C:N ratio and lowest lignin content of the shrub leaf litter examined by Schaefer et al. (1985) also had the lowest net annual mass loss (Table 4). All species examined by Schaefer et al. (1985) exhibited significant N mineralization or N loss during the first six months of field exposure. Cepeda (1986) found that the decomposition rates of black grama grass, B. eriopoda were lower than those of leaves of shrub and annual species.

The decomposition of litter under canopies of shrubs produces relatively N rich islands while the decomposition of grass litter and herbaceous plant litter

Table 4. Carbon nitrogen ratios, lignin content (%) and percent mass loss per year of leaf litter of several Chihuahuan Desert shrubs in comparison to leaf, stem litter of annual plants. (Data from Schaefer et al. 1985).

Species	C:N ratio	Lignin	Net annual Mass Loss
Chilopsis linearis	19.1	14.6	76.5
Flourensia cernua	20.7	9.6	40.8
Larrea tridentata	26.7	10.6	35.1
Prosopis glandulosa	16.1	7.8	30.6
Mixed annual plants	24.2	10.3	61.7

produces little soil organic matter or nutrient enrichment.

Generally desert shrubs have diffuse relatively deep (>1m) woody root systems (Fig. 5). Because of the responses of *L. tridentata* to small rain events and fertilization and concentration of nutrients in the upper 10 cm of soil (Fisher et al. 1987), we hypothesized that the shallow fine roots of shrubs are responsible for most of the nutrient uptake. In *L. tridentata* dominated systems, the seasonal timing as well as the frequency and quantity of rainfall has a marked effect on nitrogen availability through effects on N immobilization/mineralization processes (Fisher et al. 1987). Winter and early spring precipitation results in the production of dense stands of annual plants under the shrub canopies. The rooting depth and root biomass of these annuals is dependent upon the depth of the wetting front and duration of moist soil at depth during the growth of the annuals. This results in root:shoot ratios ranging from 1.2 to as low as 0.2 (unpublished data). Spring annuals die as soil temperature begins to increase in March and April. The death of spring annuals is generally coincident with the initiation of growth in *L. tridentata* (Gutierrez and Whitford, 1987; Fisher et al. 1987). The death of spring annuals produces a pulse of high C:N ratio dead roots (C:N ratios, 65-70, Whitford and Stinnett, 1987). The dead roots are a carbon (energy) source for microorganisms. The fungi growing in and on these dead roots immobilize N, thereby competing with shrub roots for the small quantities of N being mineralized from decomposing litter fragments (Fig. 6). Decomposing roots of annual plants continue to exhibit net immobilization for the following 6-9 months thus severely restricting N availability for annuals germinating in October and November and early shrub growth during the following year (Gutierrez and Whitford, 1987; Fisher et al. 1987). Thus successive wet periods result in the characteristic reductions in NPP found in such systems during the second of two successive "wet" years (Ludwig and Flavill 1979, Gutierrez and Whitford, 1987). Productivity of shrub dominated systems thus tends to exhibit time lags in NPP following rainfall pulses and the time lags vary from 0 to more than 1 year depending upon the immediate past history of rainfall and production of annual plants that are the sources of high C:N ratio "pulses" of dead roots.

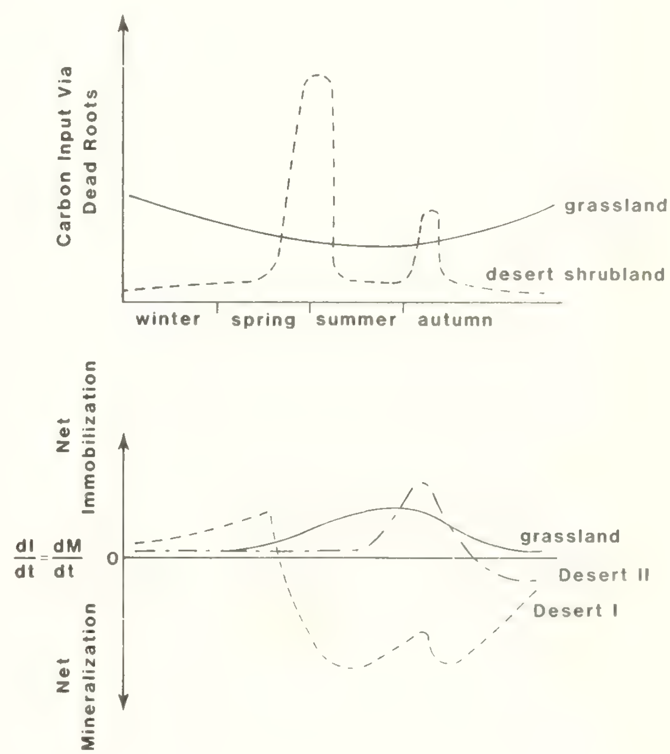

Figure 6.--Hypothesized seasonal patterns of carbon inputs to the soil and seasonal relationships of mineralization and immobilization in desert grasslands and shrublands. The carbon inputs for desert shrublands is for a year with a wet winter and spring and normal summer rainfall. The lower model Desert I is for carbon input for wet winter, spring and average summer rainfall. Desert II is for a dry winter and spring with average summer rainfall.

Primary production of black grama grasslands appears to be closely correlated with rainfall despite annual plant production equivalent to or greater than

that measured in L. tridentata areas (Pieper and Herbel, 1982). perennial grasses maintain a significant proportion of their biomass in a dense network of shallow roots (Dickinson, 1982, Pieper and Herbel, 1982). Perennial grass root systems differ greatly from shrub root systems in several important characteristics (density and nature of the roots, production of mucigels, development and species composition of rhizosheath microorganisms, and spatial relationships to annual plant roots). In grasslands annual plants grow in the interclump spaces with little or no spatial overlap with the nutrient absorbing roots of the grass clump. Rhizosheaths are common in xeric grasses (Wullstein et al. 1979, Whitford pers obs.). The material secreted from roots of grasses that bind soil particles to form rhizosheaths are mucilages (Rougier and Chaband, 1985) which may serve to attract and support free living nitrogen fixing bacteria in the rhizosheath (Mandimba et al. 1986, Reinhold et al. 1986, Wullstein et al. 1979). Thus, during periods of active translocation of photosynthate to the roots, active root growth and mucilage production may stimulate N fixation by a variety of free living N fixers (El Shahaby and Whitford unpublished data).

During periods of highest growth rates, nitrogen fixation in rhizosheaths could supply a significant proportion of the required nitrogen. Although roots of perennial grasses die and decompose, that process is probably continuous and occurs at a low rate (Dickinson, 1982). With non-symbiotic N fixation and a continuous if fluctuating rate of root turnover, it is probable that nitrogen mineralization exceeds immobilization most if not all of the time (Fig. 6). Considering these characteristics, the close linkage of grassland production to precipitation and the lack of linkage in shrublands is comprehensible. The conceptual model comparing these processes is presented in Figure 6).

As described above, a significant but variable part of the spatial-temporal variability in net primary production results from the characteristics of dominant vegetation of a landscape unit. However, the net productivity of many similar landscape units may vary in space and time, in part as a function of net import or export of organic matter. Soils in areas where organic matter accumulates have higher potential rates of N mineralization than areas exporting organic matter or that are isostatic with respect to organic matter transport (Fig. 7). These relationships are

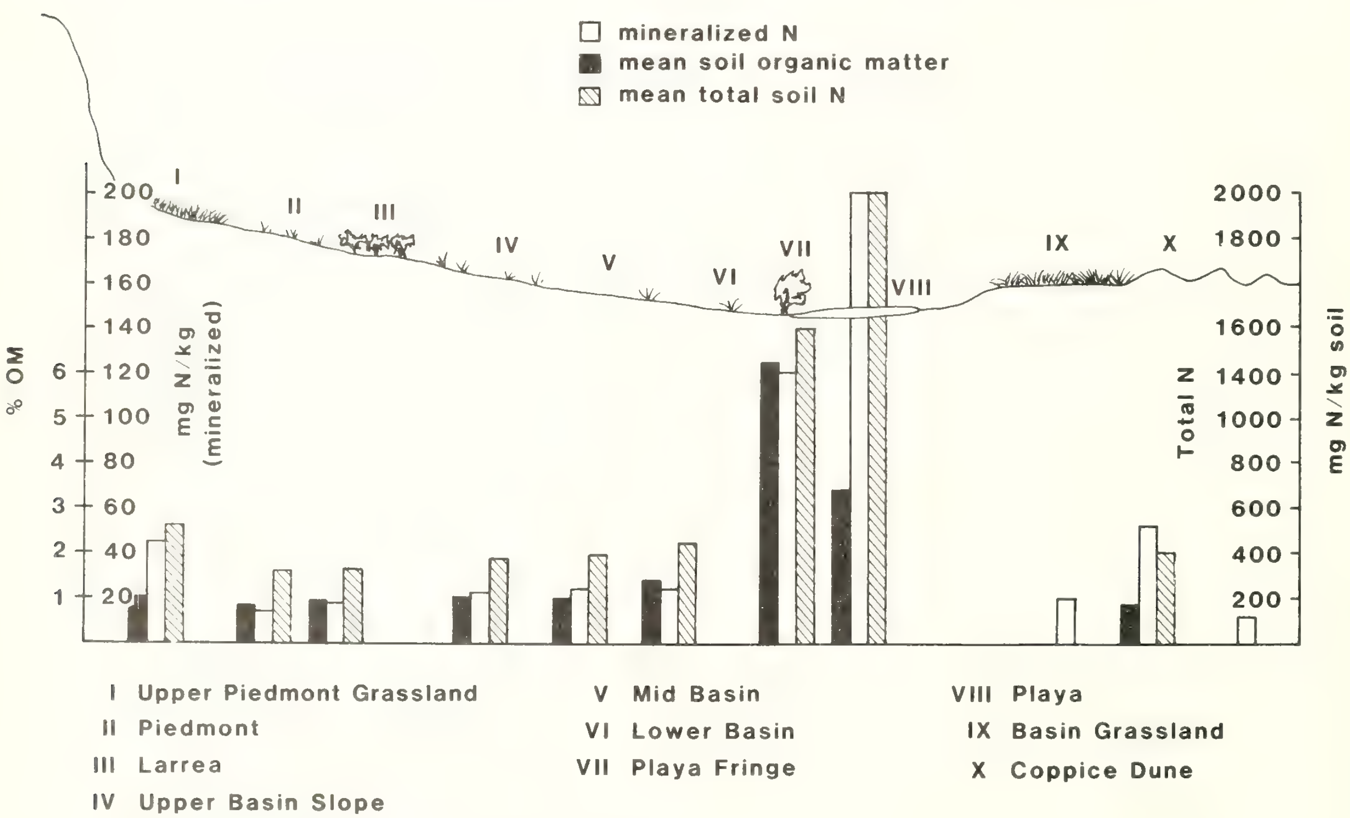

Figure 7. -- Relationships between slope and vegetation and soil organic matter, total soil nitrogen and nitrogen mineralization potential measured as mineralized nitrogen at the end of 16 weeks of laboratory incubation.

readily seen in comparisons of location with respect to slope, mean organic matter and average total soil N.

Another variable that affects soil organic matter and nitrogen is the activity of termites (Parker, et al. 1982). The subterranean termites of the northern Chihuahuan desert feed on a wide variety of organic materials (Johnson and Whitford 1970, Whitford, et al. 1982.) In areas where organic matter accumulates behind small debris dams or precipitates out of the slow moving sheet flow but where termites are abundant, soil organic matter may be quite low. This is the pattern seen on the Jornada LTER transect. The mineralization of organic matter in the guts of termites effectively eliminates that organic matter and nitrogen from the root zone of the soil.

The preceding review of the available data supports the contention that desertification of the desert grasslands of North America has had an enormous impact on the temporal linkage between precipitation and plant production. In addition, reduction of perennial grass cover and replacement of grasses by scattered shrubs or herbaceous plants has probably had a marked effect on transport processes, hence the linkage between water storage and nitrogen availability. While it is not possible to directly test some of the hypotheses developed from the existing data base, it is clear that we must have a more complete understanding of the water input, organic matter transport, nitrogen availability relationships before we can develop optimal food or fiber production strategies that can be sustained on desertified landscapes. In addition, the gradual shifts from grassland to shrubland affect populations of animals that create disturbance patches and organic matter patches. Are such patches relictual in recent shrublands? How do changes in soil and vegetation affect populations of animals that are important as pedogenic agents? We have only been able to develop some hypotheses that address such questions. The requisite data and insights will be gained only by research efforts that use experiments, simulation models and long term monitoring of key parameters in an integrated, interdisciplinary program.

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A Regional Center for New Crops and Agrisystems for Dry Lands in Mexico[1]

Kennith E. Foster and Robert G. Varady[2]

Virtually half of Mexico is arid or semiarid and is largely unsuitable for conventionally irrigated agriculture. The nation nevertheless has resolved to increase productive acreage in these regions. Success will require careful crop selection and development of innovative, adaptive cultivation systems. Establishment of a new crops and agrisystems center in Mexico is one strategy for demonstrating the feasibility of selected crops and techniques.

INTRODUCTION

Agriculture and Drylands in Mexico

According to Mexico's president, the nation's longstanding goal in agriculture is to "increase production at a higher rate than that of population growth" (de la Madrid 1984). Over the past two decades the country has accomplished this objective, but only barely, with production outpacing population by just two percent (IIED-WRI 1987). Progress has been slow and expensive, and constrained by insufficient arable terrain, limited physical resources, and scarce capital.

Under current economic planning, Mexico's agricultural sector is growing in absolute terms at an annual rate of about five percent. The sector's share of the gross domestic product has been declining steadily, however, from 14 percent in 1965 to just 8 percent in 1983 (World Bank 1985). Concurrently, a decreasing number of Mexicans belong to the agricultural labor force (36 percent in 1981 vs. 50 percent in 1965), while increasing numbers of rural residents are leaving ancestral farms for the cities and the northern frontier (World Bank 1985).

Serving as a backdrop to Mexico's agricultural development is the extreme limitation of cultivable acreage: under current criteria, less than a fifth of the nation's total land surface is considered suitable for agriculture (table 1). Only two-thirds of this area currently is under cultivation. The remaining third of the arable acreage is viewed as marginal land, terrain into which agriculture may someday be extended. As table 1 shows, Mexican agriculture relies appreciably on irrigation; more than a fifth of the nation's farmland is irrigated. And, in spite of limited water supply, irrigated acreage is increasing modestly at the rate of approximately 1.5 percent per annum (de la Madrid 1984, IIED-WRI 1987).

Table 1. Agricultural area in Mexico.

Land type	Area	Percent of total	Information source
	(million ha)	(%)	(#)
Total land	192.3	100.0	1
Arid & semiarid	101.3	52.7	2
Permanent pasture	74.5	38.7	1
Cultivable	35.0	18.2	3
Cultivated	23.9	12.4	4
Marginal	11.1	5.8	3
Irrigated	5.1	2.7	1

[1]IIED-WRI (1987).
[2]Estimate based upon digitization of areas shown in UNESCO (1977).
[3]Poder Ejecutivo Federal (1983). The document defines marginal land as the difference between cultivable land and cultivated land (cropland).
[4]Average of 24.7 million ha in IIED-WRI (1987), and 23.0 in Poder Ejecutivo Federal (1983).

Table 1 reveals a key to Mexico's agricultural prospects: more than half the land is arid or semiarid. Figure 1 shows the distribution of dry

[1]Paper presented at the Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones Symposium, [Tucson, Arizona, October 15, 1987].

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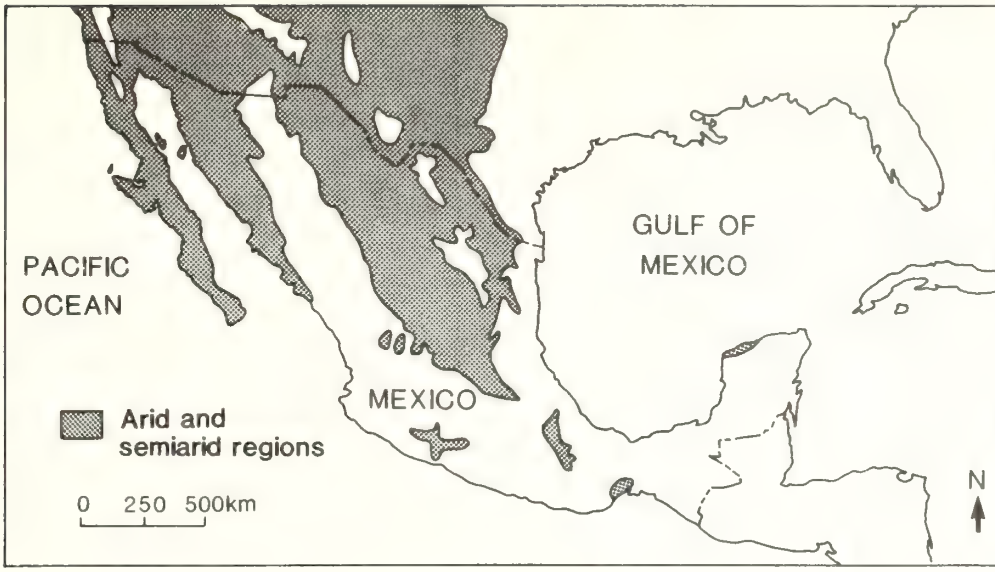

Figure 1. Arid and semiarid lands in Mexico.
Adapted from UNESCO (1977).

regions in Mexico. Table 1 also shows that large tracts of land are used for grazing. Much of this permanent pastureland lies within the country's dry zones.

Table 1 and figure 1 highlight the limitations imposed by land availability. However, they fail to disclose other important constraints to improved productivity. For decades Mexican planners hoped that modern irrigation would extend cultivation and raise yields. Current plans call for continued modest increases in irrigated acreage (Poder Ejecutivo Federal 1983).

But rises in irrigated area are being achieved at ever higher costs. As the national economy strains to meet the growing costs of materials, equipment, labor, and energy, the irrigation network takes its toll on Mexico's limited environmental resources. Irrigation is highly water-consumptive and competes with demand from industry and urbanization for diminishing supplies. And, as evidenced north of the border in the intensively irrigated southwest, salinization of fertile cropland is an inevitable consequence of irrigation. For these reasons, few observers expect significant growth beyond present levels (Johnson, et al. 1983).

Prospects for Agricultural Development

In light of Mexico's critical shortage of cropland and the above evidence, two deductions emerge:

1. If agricultural production is to increase, the nation must exploit its vast dry terrain.

2. In those areas, traditional irrigation is unsuitable due to water scarcity, environmental consequences, and cost.

These findings are wholly consistent with stated Mexican policy. The current Five-Year Plan (Poder Ejecutivo Federal 1983) and presidential assertions (de la Madrid 1984) identify the following major objectives of agricultural policy:

1. Increase production to keep apace of population growth.

2. Strive for self-sufficiency in food production.

3. Extend cultivation to areas currently considered marginal; the Plan sets the target at 7.5 million ha over the next 20 years.

4. Allocate federal resources to develop agriculture in rainfed, dryland regions.

5. Promote rational, adaptive development that protects ecosystems (especially those in fragile arid zones), and defers to social and cultural patterns.

6. Enhance employment opportunities for, and raise the income of the rural population.

7. Limit expenditures of scarce resources.

In view of the foregoing data, it is reasonable to conclude that Mexico must develop innovative ways to extend agriculture within its marginal, arid and semiarid regions. Domestic objectives will not be met by introducing traditional irrigation in the drylands, so the nation should not expect these areas to produce wheat, rice, or other staple crops.

To achieve the best outcome, agricultural efforts in Mexico's water-short areas should be directed toward evaluation of nonconventional crops

and associated cultivation systems. Wherever possible, the resulting schemes should integrate cultivation, livestock production, and aquaculture.

CENTER FOR NEW CROPS AND AGRISYSTEMS

Motivation

Since the 1960s researchers in the United States and in Mexico have been identifying plant species occurring in North America's drylands. The Sonoran Desert alone, according to one estimate, supports about 2,500 species of seed plants, of which as many as 450 have been utilized as food (Felger and Nabhan 1978). The Chihuahuan Desert, the Baja California peninsula, and other dry regions of Mexico host additional edible species. Furthermore, a large number of the region's wild plants may be valuable as fodder, fiber, medicine, chemicals, and fuel.

In particular, several domestic vegetation growthforms offer commercial potential. These include ephemeral herbs and legumes, root perennials, cacti and succulents, trees and shrubs, seagrasses, and saltgrass (Felger and Nabhan 1978, Felger 1979). The recent literature is replete with reports of research on such crops as acacia, agave, amaranth, buffalo gourd, cactus, canaigre, carob tree, coyote melon, creosote bush, eel grass, euphorbia, guayule, gumweed, jojoba, mesquite, saltbush, sunflower, tepary beans, and tumbleweed (see surveys by Peoples and Johnson 1983, and Johnson, et al. 1983).

To cultivate and commercialize nontraditional crops, scientists have developed a variety of creative technologies. Procedures have been devised for land evaluation; economic feasibility assessment; crop improvement, establishment, and maintenance; harvesting; processing; and product development. To maximize production efficiency and conserve resources researchers have adapted traditional agrisystems such as runoff water harvesting, floodwater farming, and evaporation suppression.

Together, the new crops and associated agrisystems offer the possibility of bearing low-input, high-yield, high-value products. These techniques, moreover, offer the promise of making efficient use of scarce water and fertile soils.

With suitable adaptation, the above schema can have broad applicability to Mexico's drylands. What is required is a set of new strategies for delivering and implementing proven and emerging technologies. Often, as some observers have noted, the limiting factor in such cases is not lack of proven technology, but scarcity of national resources (Niederhauser and Villareal 1986).

In the case under consideration, one possible strategy is to establish a regional center for new crops and agrisystems. The idea for such a center is not a new one. Similar propositions have been articulated in the recent past by E. M. Parsons (1983) of the U.S. Department of State (an international desert food research center): S. Taylor (1985) of the U.S. Agency for International Development (a demonstration arid lands crop production center in northern Mexico); J. S. Niederhauser and M. Villareal (1986; a model based upon a regional potato research center); and Niederhauser (1986; a regional production and training center for Africa).

The present proposal is unique in three important respects. First, it is intended specifically for improving agricultural production in Mexico's drylands. Second, it is not limited to food crops. And finally, it provides for experimentation and research in addition to demonstration.

Objectives

A center such as the one proposed herein is intended to be regional in scope. It would draw upon the strengths of established institutions on both sides of the border, pooling expertise and resources without competing or duplicating effort. The center would innovate agricultural development by combining proven, preexisting methods with promising, experimental techniques. This process would provide local growers and ranchers with alternative crops and agrisystems suited to local conditions, and thereby increase the productivity and income of participating communities.

More specifically, the proposed center would:

-- Provide physical facilities such as test plots, experimental range, greenhouses, aquaculture ponds, runoff harvesting areas, instrumented laboratories, equipped research offices, and a documentation center

-- Identify and screen candidate species

-- Assess market potential and economic viability of products

-- Conduct experiments and evaluations of crops, livestock, and fish

-- Develop and test agrisystems

-- Demonstrate practicality of approach and social acceptability of all recommendations

-- Train farmers, technicians, and scientists

Description

To achieve the above objectives, the center would integrate three major tasks: (1) plant selection and improvement, (2) agrisystem development, and (3) social and economic assessment.

Plant Selection and Improvement

A major thrust of the proposed center's activity is to develop new, locally adapted crop plants. Procedures aim to select species that are either more profitable in an absolute sense, or less risky under

prevailing environmental conditions. Accordingly, the research plan focuses on selecting, characterizing, and improving species that hold near-term potential as new crops for Mexico's drylands. Center personnel would evaluate species yielding food products, animal feed, fuel, fiber, pharmaceuticals, and other saleable commodities. Indigenous, well-adapted species having demonstrated economic potential would be accorded highest priority.

Plants from marginal arid and semiarid lands are known for the complex arrays of secondary metabolites they frequently produce. Often, these substances arise as accommodations to the extreme conditions of heat, desiccation, and herbivory to which the plants are exposed. Because of these phytochemical adaptations, such plants represent a rich, largely unexploited source of chemicals.

To identify plants possessing marketable value, University of Arizona researchers have developed novel systems for screening arid-adapted species. These procedures begin by identifying species used by indigenous peoples, then consider such parameters as biomass yields, types and percentages of phytochemicals, and local unit production costs.

The proposed screening program considers production and processing requirements, nutritional or economic value of the products, and a host of location-specific variables. Plant ecophysiology is a major consideration since ability to cope with heat and water stress, poor soil quality, or salinity provides clear advantages over conventional crops.

The screening and development procedures were devised and tested in response to the need for new crops in regions of the Sonoran Desert, where conventional irrigation no longer can be maintained economically. Unlike the U.S. Department of Agriculture's screening system which employs criteria appropriate to temperate climates and typical agricultural soils, the "Arizona Method" was designed specifically for use in marginal drylands. This method takes into account the unique constraints imposed by arid environments on plant growth and agricultural practices.

Agrisystem Development

Arid and semiarid regions are characterized by rainfall regimes that are highly variable temporally and spacially. Generally, these regimes do not permit conventional cropping systems without supplemental irrigation.

One approach for overcoming the climatic limitations found in drylands focuses on introducing plants that are highly water-efficient (see above). Another, often complementary, approach introduces cropping systems that increase available water by using larger areas. The following alternative strategies may be employed, individually or in tandem, within this "extensive" approach:

-- Allow widely spaced plants to take up moisture through root systems that tap larger soil volumes, or that reach deep stored water (cereals, shrubs, and rangeland trees are crops that can be cultivated in this manner)

-- Employ quick-maturing annual plants that can make use of moisture during the short periods it remains available

-- Exploit existing concentrations of surface runoff, or manipulate large areas to induce runoff that may be captured and stored for later use (water harvesting is such a process)

As new, economically promising species are identified and improved, appropriate cultivation systems need to be formulated and refined. Available agrisystems include agroforestry, perennial culture, floodwater farming, water harvesting, relay or mixed cropping, and intercropping new species within established systems.

In Mexico's marginal drylands, labor-intensive agricultural strategies may be preferable to capital-intensive, highly mechanized, energy-intensive practices. For this reason, a key aspect of agrisystem development at the proposed center would be to examine and assess energy balances. Estimates of inputs such as fuel, fodder, mechanical or animal traction, human labor, and solar energy would inform choices of crops and associated production systems. A further consideration in maintaining overall energy balance is that manufacture, transport, and application of synthetic fertilizer is far more energy-intensive than use of available manure and other nutrients.

As noted, maintenance of agricultural systems in drylands depends primarily upon the source, supply, and management of water. Precipitation, diverted or pumped river or groundwater, and run-on are the sources of soil moisture for most plants; major system losses occur through evaporation, transpiration, runoff, and drainage. These parameters would be manipulated via techniques such as water harvesting, floodwater farming, and evaporation suppression. In some systems it may be possible to provide long-term storage of moisture in the soil to permit dry-season cropping. And, by means of plant breeding and development techniques, active periods of crop growth may be made to coincide with relatively short rainy seasons. To take advantage of all such possibilities, plant development and agronomy would be closely integrated.

Balancing the biogeochemical components of a farming or livestock system also is crucial to its effectiveness. System inputs include nutrients released from the soil or carried in rainfall and runoff, fixed nitrogen, and supplements of manure or other fertilizers. Losses arise from soil erosion, gaseous diffusion, and removal of plant materials at harvest. Successful introduction of new crops requires careful maintenance of the nutrient equilibrium.

In all cases, researchers would balance the merits and disadvantages of available alternatives. Additionally, implemented techniques would strive to minimize topsoil loss, waterlogging, salinity, and

other environmental degradation that often accompanies cultivation.

Social and Economic Assessment

New, economically attractive alternatives are likely to be welcomed by farmers and ranchers. However, communities may be more willing to adopt agricultural systems if they require low capital investments and only minimal changes in established cultivation and herding patterns.

In a noted essay titled "They Do not Want More," an observer (Nair 1961) described a village in India, where for more than three years every cultivator had refused free irrigation water. To many this anecdote epitomized the perceived backwardness, intransigence, and irrationality of farmers in the developing world. The villagers' obstinacy symbolized the barriers to modernization.

More sympathetic views of peasant rationale now prevail. It is generally understood that there are ample reasons why villagers might refuse free water. Cultural practices or religious beliefs provide one explanation: farmers may have believed that the "essence" of the water had been removed by upstream hydro works, rendering the residual water impure for growing crops. Economic and political reasons for skepticism also abound: cultivators often are rightfully suspicious of hidden long-term costs, and are wary of dependency on sources beyond their control.

The introduction of new crops and farming techniques, like the introduction of free water, constitutes an incursion into established modes of production and livelihood. Thus, in deference to local customs and conditions, programs at the proposed center would assess the many social, economic, and political factors that could affect the success of new crops and agrisystems.

As a foundation social scientists at the center would identify and evaluate some of the factors associated with agricultural systems. In Mexico, Hispanic, Catholic, Native American ritual calendrical considerations for centuries have dictated planting, processing, and consumption of plants. Additional cultural and political factors such as the roles of family, class, gender, religious institutions, village organization and external relations, environmental perception, and the effects of regulation and patronage on use of water and land are central to rural society and influence agrarian practices. No less important are such local economic factors as production, storage, and marketing costs; availability of credit, equipment, seeds, and inputs; nature of business practices; and existence of supportive infrastructure. Other socioeconomic aspects of subsistence systems are less well understood, but exert considerable influence on agriculture.

Before recommending new crops or agrisystems, the center staff would examine all the above variables and evaluate their effects on prospects for successful innovation. If the Indian village described above provides a caveat, it is not that new agricultural technology is impossible to introduce. Rather, the example illustrates that to succeed, any introduction should be preceded by cautious and sincere efforts to understand and accommodate the context of existing practices.

Participating Institutions

As noted, the proposed center would serve regional needs and draw personnel from both the United States and Mexico. Numerous organizations in the two countries already are engaged in related agricultural development efforts. To be most effective, the new center would be affiliated with sister institutions, and would draw upon the resources of these establishments.

In Mexico alone, dozens of government agencies and research institutions include dryland development within their purview. Many of these organizations, by virtue of their location in deserts or semiarid regions, are dedicated to improving local agrarian conditions. Past collaboration between these centers and their U.S. counterparts has demonstrated a strong willingness to share information and technology.

The listing in table 2 below identifies some of the prominent Mexican institutions concerned with dryland agriculture (Hutchinson and Varady 1988, Johnson, et al. 1983).

Table 2. Mexican Institutions involved in Arid Lands Development.

-- Centro de Ecodesarrollo, México, D.F.
-- Centro Ecológico de Sonora (CES), Hermosillo
-- Centro de Estudios Superiores del Estado de Sonora (CESUES), Hermosillo
-- Centro de Investigaciónes Agricoles del Noroeste, Obregon, Sonora
-- Centro de Investigaciónes Biológicas de Baja California Sur (CIB), La Paz
-- Centro de Investigaciónes Científicas y Tecnológicas de la Universidad de Sonora (CICTUS), Hermosillo
-- Centro de Investigación y Desarrollo de los Recursos Naturales de Sonora (CIDESON), Hermosillo
-- Centro de Investigaciónes Forestales y Agropecuarias en el Estado de Baja California Sur, La Paz
-- Centro de Investigación en Química Applicada (CIQA), Saltillo, Coahuila
-- Centro Regional para Estudios de Zonas Aridas y Semiáridas, Salinas, San Luis Potosí
-- Comisión Coordinadora del Programa de Desarrollo de las Franjas Fronterizas y Zonas Libres (CODEF), México, D.F.
-- Comisión Nacional de las Zonas Aridas (CONAZA), Saltillo, Coahuila
-- Consejo Nacional de Ciencia y Tecnologia (CONACYT), México, D.F.

Table 2. (continued)

-- Coordinación General del Plan Nacional de Zonas Deprimadas y Grupos Marginados (COPLAMAR), México, D.F.
-- Escuela Superior de Agricultura Hermanos Escobar, Ciudad Juarez, Chihuahua
-- Instituto de Ecología, México, D.F.
-- Instituto de Geografía, Universidad Nacional Autónoma de México, México, D.F.
-- Instituto de Investigacion de Zonas Desérticas, San Luis Potosí
-- Instituto de Investigaciónes de Estudios Superiores Noroeste (IIESNO), Hermosillo, Sonora
-- Instituto Nacional de Investigaciónes Forestales y Agropecuarias, México, D.F.
-- Instituto Nacional de Investigaciónes Pecuarias, Chihuahua
-- Instituto Nacional de Investigaciónes sobre Recursos Bióticos, Xalapa, Veracruz
-- Instituto Tecnológico de Sonora, Obregon
-- Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila
-- Universidad Autónoma Chapingo, Chapingo, México

CONCLUSION

The ideas discussed herein are proposed as a potential strategy for improving agricultural production in Mexico. As shown, much of the country's territory is dry and marginally productive. Cultivation will have to be extended to these regions if the agricultural sector is to improve. The proposed center would offer appropriate alternative crops and agrisystems, and mechanisms for introducing these innovations in the drylands of Mexico.

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SISTEMA INTEGRAL DE PRODUCCION AGROPECUARIA EN TEMPORAL EN EL LLANO DE AGUASCALIENTES, MEXICO[1]

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Resumen.--Se evaluó en sistema agropecuario de temporal basado en cultivos básicos y forrajeros con la finalidad de lograr la autosuficiencia y el arraigo del productor a su región. Para tres años de evaluación el sistema logró cubrir las necesidades básicas alimentación de una familia.

INTRODUCCION

El Llano de Aguascalientes se localiza dentro de las zonas áridas de México, donde la precipitación es escasa y de mala distribución en el verano y se presenta en un periodo no mayor a 90 días, lo cual ocasiona una estación de crecimiento del cultivo de solo 84 días. Los productores agropecuarios de esta región se dedican principalmente al cultivo de maíz y frijol bajo condiciones de temporal, los cuales utilizan para el autoconsumo familiar y son el producto básico para la alimentación.

La situación es condicionante para la permanencia del productor en su predio, ya que si el año fue bueno en precipitación y se logró obtener suficiente grano de maíz y frijol o forraje para alimentar su ganado, él no emigrará a las grandes ciudades o al extranjero, si fue malo él emigrará (Claverán, 1982).

En esta región, la agricultura de temporal ocupa aproximadamente a 65,000 habitantes en una superficie de 110,000 ha de las cuales 88,000 se destinan a maíz de temporal y 22,000 al frijol. La precipitación promedio anual es de 337 mm; sin embargo, la precipitación que ocurre en el periodo del cultivo es de 218 mm. La condición climática que prevalece, en general, en esta zona hace que se tenga un alto número de parcelas siniestradas por los bajos o nulos rendimientos obtenidos.

Como promedio de los últimos ocho años, se reporta que para maíz la tasa de siniestro fue del 66% mientras que para frijol del 65%, obteniéndose rendimientos promedios de sólo 128 kg/ha de grano de maíz y de 28 kg/ha de frijol (México, 1986).

Por otra parte, los productores de esta región cuentan con una superficie agrícola de 8.2 ha en promedio y sólo el 60% fertiliza los cultivos mencionados ya que los rendimientos no cubren los costos del fertilizante.

Se estima que los productores destinan el 54% de sus ingresos totales a la alimentación y que el 80% tienen otra actividad fuera de su predio con el fin de solventar la economía familiar (Díaz, 1984).

Con el objeto de lograr el arraigo del productor a su predio y mejorar su nivel de vida, se planteó integrar un sistema de producción agropecuario bajo condiciones de temporal con una superficie de 8 ha para la producción de productos básicos para la alimentación, con cultivos que generen ingresos por los excedentes y cultivos forrajeros que permitan alimentar animales para la obtención de proteína animal.

Para lograr tal objetivo se determinaron los rendimientos de alimentación básica para una familia promedio de seis miembros, así como la necesidad de forraje para alimentar a un rebaño caprino con la finalidad de fijar una meta que indique el grado de logro obtenido.

MATERIALES Y METODOS

El estudio se desarrolla en El Llano de Aguascalientes, en las instalaciones del Campo

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[1]Ponencia presentada en la Reunión sobre Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en las Zonas Aridas. (Tucson, Arizona, E.U.A., 12-16 de Octubre de 1987).

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Agrícola Experimental Auxiliar Sandovales (CAEAS), perteneciente al Instituto Nacional de Investigaciones Forestales y Agropecuarias en el estado de Aguascalientes.

El CAEAS se localiza en el centro de México, dentro del estado de Aguascalientes, y geográficamente en el paralelo 102°17' al oeste de Greenwich y en el 22°10' de latitud norte a una altura de 1,950 msnm.

El clima característico de la región de El Llano pertenece al tipo BSK (w)(e), según W. Koeppen y modificado por García en 1970, el cual corresponde al clima seco estepario con temperatura media anual entre los 12 y 18°C con tendencias de oscilaciones extremosas mayores a 14°C, con temperatura del mes mas cálido superior a 18°C y la del mes mas frío entre -3 y 18°C. La precipitación media anual registrada en los últimos 10 años es de 337 mm, ocurriendo en el verano el 60% y el resto en los meses invernales.

Los suelos del CAEAS son del tipo predominante en la región los cuales son delgados y de baja fertilidad con textura arcillo-arenosa y con problemas de compactación.

El presente estudio se inició en 1983, mediante participación de investigadores de varias disciplinas, por lo que los cultivos asignados se establecieron de acuerdo con las recomendaciones de paquetes tecnológicos generados por investigaciones realizadas en terrenos del CAEAS.

El estudio contempla las fases siguientes:

1. La factibilidad agronómica para sustentar a la familia y los animales, con los rendimientos obtenidos de los cultivos establecidos en una superficie no mayor de 8 ha.

2. La evaluación económica del sistema de producción con todos sus componentes en operación.

Los cultivos se establecieron en una superficie de 8 ha, de las cuales se utilizaron 2 ha para maíz, 1 ha para frijol, 2 ha para forraje, 1 ha para papita guera y 2 ha para nopal tunero. Con excepción del nopal tunero y la papita guera, el resto de los cultivos anuales se rotaron año con año dentro del mismo terreno.

Con la distribución espacial mencionada, se pretende que el productor obtenga los productos básicos para su alimentación y crear un excedente con fines de comercialización, el cual provendrá principalmente de la papita guera y el nopal tunero, y de esta manera obtener ingresos para adquirir otros productos básicos que no se pueden producir en el predio.

Es importante mencionar que la papita guera es un cultivo no domesticado perteneciente al género _Solanum_ siendo identificadas dos especies principales que son _cardiophyllum_ y _ehrenbergii_. Se cree que su origen es del centro de México y aparece sin siembra alguna en terrenos cultivados de maíz y frijol bajo temporal. El tubérculo es de consumo humano y los productores lo cosechan para autoconsumo y su venta en ciudades donde tiene una alta demanda.

Los caprinos entrarán en funcionamiento en la Fase 2 y serán del tipo predominante en la región, donde los rebaños tienen algunas características de la raza Nubia. Se utilizarán cinco cabras y un semental, la alimentación será del forraje cosechado de la superficie de forrajes y de los esquilmos del maíz y frijol, se espera obtener con esto un rendimiento medio de 1,200 litros de leche anuales del sistema.

RESULTADOS Y DISCUSION

Los resultados siguientes corresponden a la Fase 1 del estudio y son para los años 1983, 1984 y 1985.

Los rendimientos esperados para cada cultivo, así como los requerimientos familiares, fueron fijados al iniciar el estudio (Cuadro 1). Los requerimientos de una familia de seis miembros se tomaron con base en un estudio efectuado por el Programa Nacional de Alimentación del Gobierno Federal, el cual indica un requerimiento anual de 780 kg de grano de maíz y de 216 kg de frijol (PRONAL, 1983).

Cuadro 1. Superficie y rendimientos esperados para los cultivos del sistema integral de temporal.

Cultivo	Sup. (ha)	Producción esperada (ha)	Requerimiento Familiar
Maíz	2	600 kg	780 kg
Frijol	1	400 kg	216 kg
Forraje	2	1.9 ton[1]	3,800 kg[2]
Papita guera	1	1,200 kg	
Nopal tunero	2	440 cajas	
Total	8		

[1]Materia Seca incluyendo esquilmos.
[2]Requerimientos del rebaño.

En los casos de la papita guera y el nopal tunero no se fijaron los requerimientos familiares ya que no constituyen alimentos de necesidad básica.

Por su parte, los rendimientos esperados se calcularon con base en los resultados de investigaciones efectuadas en el CAEAS.

En el caso del maíz se obtuvo un rendimiento medio anual de 733.6 kg en el sistema, en 1985 fue inferior al esperado (581 kg); sin embargo, el balance indica que se produjeron 134 kg de -

maíz por arriba de lo esperado, siendo realmente crítico un solo año (Cuadro 2).

Los productores de la región obtuvieron un rendimiento de sólo 500, 130 y 117 kg/ha de maíz para los años de 1983, 1984 y 1985, y se presentó siniestro en el 13.3 , 54.6 y 46.4% de las parcelas de maíz en los mismos años de estudio (Méx. SARH[1], 1986).

Cuadro 2. Rendimientos de cultivos establecidos en el sistema de producción agropecuario de temporal para tres años de estudio.

Cultivo	1983	1984	1985	Balance $\bar{x}$ anual
Maíz	760	860	581	+ 134
Frijol	360	940	457	+ 180
Papita	1,500	3,090	3,318	+ 1,436
Nopal[1]				
Prec. (mm)	294	292	349	

[1]Años de establecimiento del nopal tunero.

Para el frijol se ha obtenido un excedente de 180 kg como promedio de los tres años, 1983 fue el año más crítico a causa de que la precipitación fue escasa en la etapa de floración. Al tomar en cuenta que una familia requiere de 216 kg de frijol por año se creó un excedente de 369 kg en promedio por año, lo cual puede destinarse a la comercialización.

Para los mismos años de estudio, el productor regional obtuvo 188, 90 y 91 kg de grano de frijol por hectárea y existió una tasa de siniestros en las parcelas cultivadas con frijol de 30, 57.6 y 34% (Méx. SARH1, 1986).

El cultivo que todos los años ha mostrado excedentes es la papita guera, ya que el rendimiento esperado ha sido superado en promedio con 1,436 kg por año y en ningún año se ha obtenido rendimientos inferiores a lo programado.

El nopal tunero se encuentra en el periodo de establecimiento por lo que no se menciona rendimientos ya que el producto del cultivo es la fruta, la cual se presentan a partir del quinto año de la plantación.

Los forrajes que se han establecido en el sistema de producción integral son la avena y el sorgo x sudan, donde se obtuvieron rendimientos de 900 kg/ha de materia seca de avena como promedio de 1983 y 1984 y de 750 kg/ha de materia seca para el sorgo x sudan en 1985. La producción de esquilmos ha sido significativa ya que han aportado el 75% del suministro total de forrajes dentro del sistema.

[1]SARH, Secretaría de Agricultura y Recursos Hidráulicos.

La producción media total de forraje disponible es de 6.94 ton de materia seca lo cual ha proporcionado excedentes en forraje tomando en consideración las necesidades del hato caprino (Cuadro 3).

Cuadro 3. Rendimientos de forraje y esquilmos en 2 ha del sistema de producción agropecuario de temporal para tres años de estudio.

	1985 Avena	1985 Avena (ton)	1985 Sorgo x Sudan
Forraje (2 ha)	2.20	1.36	1.48
Esquilmos	5.28	6.10	4.41
Total:	7.48	7.46	5.89
Balance[1]	+3.68	+3.66	+2.09
Precipitación (mm)	294	292	349

[1]Producción - Requerimientos.

Los excedentes en forraje disponible que cada año se han presentado han sido capaces de formar una reserva de 9.4 ton de materia seca, la cual puede ser utilizada en los años de nula producción de forraje o de incrementar el número de caprinos.

Tiscareño, et al., en 1983 reportan en el estado de Zacatecas, México, un sistema de producción agropecuario de temporal para la producción de leche basado en forrajes de corte y granos básicos para autoconsumo, donde se registran 290 mm de precipitación. La rentabilidad del sistema fue de 377,702 pesos, mientras que el sistema tradicional de maíz para grano fue de 256,460 pesos, ambos en una superficie de 20 ha.

Las condiciones climáticas que se han presentado en los años de estudio, han sido desicivas en los rendimientos obtenidos ya que la precipitación captada por el cultivo ha sido escasa y sin uniformidad.

En 1983 se captaron 294 mm en el periodo lluvioso de junio a septiembre, abarcando el cultivo 79 días de dicha estación, el cultivo más afectado fue el frijol. Para este año la precipitación en el periodo lluvioso fue del 77% con respecto al total anual. La Figura 1 presenta la gráfica de distribución de la precipitación.

En la Figura 1 se presentan los requerimientos de agua de los cultivos expresados en la evapotranspiración al 50% (ETP.5), ya que las plantas sólo muestran condiciones óptimas de humedad en pequeños periodos de la estación de crecimiento pero que la mayor parte de la estación de crecimiento muestran déficit de humedad.

En 1984 se observó una distribución más --

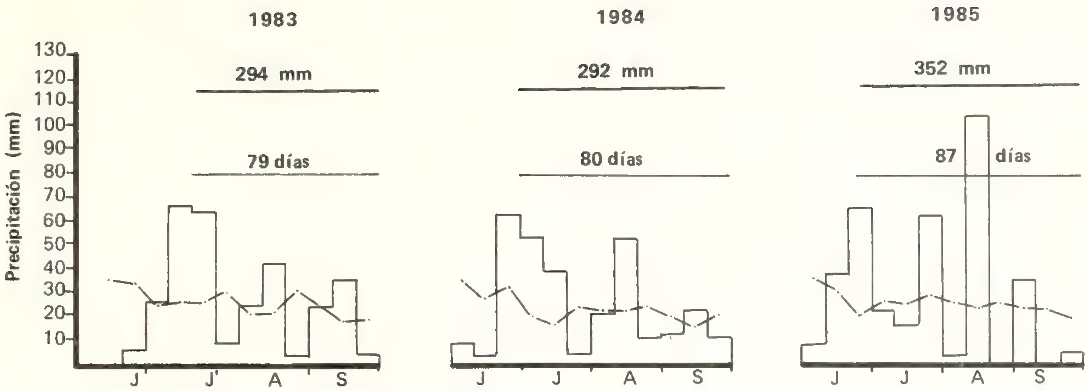

Figura 1. Distribución de la precipitación, evapotranspiración al 50 o/o por decena mensual y ciclo vegetativo del cultivo en la estación lluviosa en El Llano, Ags., México.

uniforme, donde los déficit de humedad fueron menos pronunciados, por lo que se obtuvieron los mejores rendimientos de los cultivos comparados con 1983 y 1985. Para 1984 los ciltivos abarcaron 80 días del periodo lluvioso y se captó el 73% de la precipitación total anual.

En 1985 la precipitación mostró la mayor irregularidad ya que se presentaron eventos de más de 100 mm en agosto de manera torrencial, provocando que poca agua fuera aprovechada por la planta y que por lo tanto existió un déficit cuando se encontró en la formación del grano. En este año los cultivos abarcaron 87 días de la estación lluviosa, y se captó el 75% de la precipitación total anual.

En esta región son comunes los eventos torrenciales, que ocasionan pérdidas de suelo y escasa retención de humedad; Martínez, reportó pérdidas de suelo de 12.6 y 16.8 ton/ha para 1980 y 1981 con precipitaciones de 94 y 252 mm, respectivamente, en terrenos del sistema de producción en estudio.

Por último, el sistema logró ser autosuficiente en maíz, frijol, forraje y papita guera. El nopal tunero aún no rinde frutos por lo que su evaluación será en la Fase 2. De acuerdo con la superficie asignada se tuvo altas producciones de papita guera (3,318 kg) por lo que se considera excesiva y por lo tanto conviene reducir la superficie.

CONCLUSIONES

1. Para 1983, 1984 y 1985 los cultivos lograron rendimientos satisfactorios por lo que el sistema de producción fue autosuficiente.

2. La papita guera permite tener excedentes de comercialización con precipitaciones bajas, lo cual disminuye el riesgo biológico del sistema.

3. El cultivo más afectado por la sequía fue el sorgo x sudan por lo que la avena fue más conveniente para el sistema de producción.

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MANEJO ECOLOGICO DE UN BOSQUE DE PINOS PINONEROS EN TAMAULIPAS

Humberto Suzan Azpiri[1] y Jose Antonio Galarza[2]

Resumen.- En poblaciones de _Pinus nelsonii_ se han realizado estudios dasométricos, demográficos, de clasificación de sitios forestales, de germinación de semillas , de composición florística y de uso de plantas por los habitantes de la zona. Se ha encontrado un marcado efecto de ladera, uso múltiple del bosque y efectos de sobrecolecta en las poblaciones naturales.

INTRODUCCION.

"... son mejores que los de Castilla". Alvar Núñez Cabeza de Vaca (1528-1536).

Los pinos piñoneros de Norteamérica han sido utilizados con muy diversos fines por [illegible] como una fuente de productos alimenticios, maderables, ceremoniales y como leña, siendo así un elemento básico en la economía familiar de los habitantes de regiones donde existen pocos medios de subsistencia, especialmente en los meses de otoño e invierno cuando se da la cosecha de semillas, siendo por lo tanto un recurso vital, cultural y alimenticiamente. (Fogg 1965).

El primer occidental en tener contacto con los piñoneros de América, y con las etnias que lo aprovechaban en el Norte del país y Sur de los Estados Unidos aparentemente fue Alvar Núñez , náufrago de la catastrófica expedición de Pánfilo de Narváez en 1528, encontrando probablemente poblaciones de _Pinus cembroides_, o de _Pinus edulis_ como reporta Lanner (1981), basado en los relatos del libro "Naufragios y Comentarios".

El contacto contínuo del hombre con el piñón, ha ocasionado que las características de las poblaciones, así como la composición florística y estructural del bosque estén íntimamente relacionados con la historia de los habitantes que utilizan este recurso.

La mayor diversidad de especies productoras de piñon del mundo, está en México con 15 sp según Bailey y Hawksworth (1987), destacando como las dos más productivas en el país _Pinus cembroides_ y _Pinus nelsonii_.

Pinus cembroides presenta un amplio rango de distribución en las Sierras Madre Oriental y Occidental, y ha sido objeto de diversos estudios entre los que destacan los de Robert (1977), y Passini (1982).

Pinus nelsonii es una especie de distribución restringida al Noreste del país, poco estudiada y con una producción anual de semillas, característica poco común en la mayoría de los pinos mexicanos; La testa de su semilla es muy dura y de mayor grosor que la de otras especies, lo que podemos observar al compararlas con las de _P. cembroides_, por lo que la incidencia de ataques por insectos es baja.

La almendra de _Pinus nelsonii_ es de un color blanco y sabor agradable (es preferida por los habitantes de la zona), y presenta un porcentaje de proteiñas similar al de _P. cembroides_, pero una mayor proporción de fibras, haciéndolo atractivo nutricionalmente.

Estas propiedades de la semilla, asi como su alta capacidad para sobrevivir en zonas semiáridas y frías determinaron que el Instituto de Ecología y Alimentos de la U.A.T. lo considerara como una especie de importancia económica actual y potencial que debiera ser estudiada con detenimiento dentro del proyecto "Recursos Vegetales del Noreste".

Para _Pinus nelsonii_ actualmente contamos con información descriptiva de su autoecología en Suzán (1985,1987) donde se reporto su distribución geográfica; y se seleccionó una población piloto en el Cañon del Soldado Municipio de Miquihuana Tamaulipas a unos 2,000 msnm. La localidad es de clima seco semiseco templado, con rocas calizas del cretácico, y con suelos calcáreos, someros y con un Ph neutro Para su descripción se formaron tres estratos verticales (E1 ladera Sur, E2 margenes del arroyo, E3 ladera Norte), .pa donde se realizo un muestreo aleatorio

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estratificado por cuadrantes de 20m por lado analizandose la distribución espacial, sus características dasométricas, su estructura de edades, y su producción de conos, para realizar una clasificación de sitios forestales, y estudiar la relación clima-crecimiento.

OBJETIVOS

Los objetivos del presente trabajo son conjuntar en base a la información ecológica obtenida algunas sugerencias de manejo de la especie, interesándonos a su vez estudiar las variables dasométricas de la población, estimar la producción semillera del bosque, realizar una clasificación de los sitios forestales, iniciar estudios sobre conos y germinación de semillas, describir la vegetación y fauna asociada, y generar una lista de especies útiles de la localidad.

METODOLOGIA.

- Con las variables dasométricas de la población (Altura, Altura a la base de la copa, radio de cobertura, edad, diámetro a 1.3m, número de conos y número de marcas) se realizó un Análisis de componentes principales.

- Para la clasificación de los sitios forestales de la población piloto se determinaron en cada uno de los cuadrantes muestreados el número de adultos, el número de plántulas, el de piñas producidas por sitio (1985), el área basal total, la cobertura vegetal y su ubicación en las laderas. Con estas variables se realizó un análisis de cúmulos.

- Para analizar las características de los conos y germinación de semillas en condiciones de vivero se colectaron todos los conos de individuos dominantes de gran tamaño en las siguientes localidades: Colonia la Peña y Cañon del Soldado municipio de Miquihuana; y la Joya de Herrera municipio de Bustamante. A los individuos colectados se les registraron sus características dasométricas habituales. A cada piña colectada se le midió el largo, ancho, peso, su número de semillas, y el peso de las semillas. Se realizó un análisis de componentes principales para analizar las relaciones entre estas variables. Los ensayos de germinación se efectuaron con las semillas colectadas, estudiando las diferencias en porcentajes y tiempos de germinación de los árboles padre, y analizando también el efecto de sombra (90% , 75%, 50%, 25% de sombra y control a plena luz) en un experimento factorial 5 por 12 .
Para eficientizar la germinación en viveros, se analizó el efecto de dos tipos de escarificación mecánica (lijado y fractura), y dos químicas (HCL y H_2SO_4), con 3 tipos de estratificación a 4 grados centígrados (1 y 2 meses previo a la escarificación, y un mes posterior a la estratificación), realizandose en una camara ambiental a temperatura , humedad y fotoperiodo constante quedando un experimento factorial de 5 por 4 (por los testigos).

-Entre Mayo de 1986 y Mayo del presente año se han realizado muestreos de vegetación en diversos bosques de coníferas del estado, con el objetivo de caracterizarlos fisonómica estructural y florísticamente. De estos muestreos 10 se han realizado en bosques de pinos piñoneros, basándose en cuadrantes de 20m por lado para vegetación arbórea, 10m para arbustiva, y 1m para el estrato rasante de la vegetación. Las variables consideradas en este análisis son : especie, altura, dap, a.b.c., y dos radios de cobertura para árboles; altura y dos diámetros de cobertura para arbustos; y cobertura para herbáceas. Se ha registrado también los parásitos, depredadores y especies animales relacionadas con el piñon.

-Los listados de especies colectadas en la comunidad se compararon con el banco de datos de las plantas útiles del estado, generandose un listado de plantas utilizadas por los habitantes del bosque.

RESULTADOS.

-La población piloto del Cañon del Soldado, se encuentra poco alterada, teniendose una mayor densidad en los estratos E2 y E3 (657.3 y 606.1) ind /ha, que en E1 (337.5) ind/ha. En el cuadro 1. podemos ver las estimaciones del tamaño de la población, y las tendencias detectadas con respecto a la distribución espacial. En E1 y E2 se observan tendencias al contagio, en tanto que en E3 a la aleatoriedad. En E1 las mayores condiciones de insolación y en E2 la alta competencia con individuos de otras especies (es la base del arroyo) pueden ser las causas de esta distribución contagiosa. Con las estadísticas descriptivas de las diferentes variables, consideradas para los individuos se puede apreciar que los árboles son uniformes , de pequeña altura, con la base de la copa baja , los radios de cobertura uniformes y los diámetros pequeños, las diferencias existentes en las estructuras de edades indican que la carencia de juveniles en el primer estrato puede ser el resultado de condiciones de una mayor insolación, a una sobrecolección de semillas (es el sitio más abierto y accesible), y a un sobrepastoreo detectado en el área.

Cuadro 1.- Descripción de la población piloto.

	E1-A	E2-B	E3-C	E2-A	E2-B	E2-C	E3-A	E3-B	E3-C
DENSIDAD	337 IND/HA			657 IND/HA			606.1 IND/HA		
VAR(X)/MED(X)	3.22 **			11.96**			1.16		
# DE IND.	42	9	3	89	81	93	102	34	78
DAP (cm)	7.3	1.3		7.4	1.4		7.7	1.7	
ALT-BAS-COPA (m)	0.7	0.3		0.7	0.6		0.8	0.4	
ALT (m)	3.6	1.7		3.5	1.8		3.2	1.7	
RAD- COB (m)	1.5	0.5		1.5	0.5		1.4	0.5	
CONOS	5.2	0.4		4.3	0.1		4.1	0.1	

**Rechazada la hipótesis de aleatoriedad con un nivel de significancia del .05%.
A= árboles = de 3cm de diametro; B= árboles de 3 cm.
C= plántulas.

Al realizarse el Análisis de Componentes Principales (ACP) de las variables por cada estrato los resultados no arrojaban ninguna diferencia en la estructura de correlación de las variables como se mencionó en Suzán (1985), por lo que se realizó un análisis para toda la población. En el cuadro 2, podemos observar los resultados del ACP para toda la población, la matriz de correlaciones nos indica una fuerte asociación del DAP con la altura y el RC; así como una asociación media con la edad y el numero de marcas. La ABC presenta bajas correlaciones, y la edad y numero de piñas permanecen ligeramente independientes.
Los tres primeros componentes explican el 83% de la variación. El primero de ellos está conformado por la altura, DAP, RC y numero de marcas, explicando el 61% de la variación, y se puede interpetar como el grupo de variables resultado del crecimiento individual, en tanto que el segundo explica el 13% de la variación,

Cuadro 2.- Análisis de Componentes Principales de los árboles.

N=358.	MATRIZ DE CORRELACIONES						
	DAP	ALT	R.C	A.B.C.	EDAD	MARCAS	CONOS
DAP	1	0.85	0.85	0.39	0.63	0.72	0.48
ALT		1	0.82	0.47	0.61	0.62	0.51
R.C			1	0.32	0.58	0.64	0.55
A.B.C.				1	0.32	0.21	0.16
EDAD					1	0.42	0.34
MARCAS						1	0.52
CONOS							1

COMPONENTES	C1	C2	C3
PROP DE LA VARIACION	0.61	0.13	0.08

EIGENVECTORES	C1	C2	C3
DAP	0.447	0.05	-0.017
ALT	0.440	0.109	-0.021
R.C	0.433	-0.095	-0.088
A.B.C	0.233	0.817	0.460
EDAD	0.351	0.151	-0.561
MARCAS	0.376	-0.306	0.222
CONOS	0.313	-0.431	0.658

conformado por la ABC.

-Para determinar la relación de los sitios forestales, se realizó un análisis de cúmulos en base a un esquema aglomerativo con distancias promedio a los centroides. El dendrograma resultante se presenta en la figura 1. La separación entre los cuadrantes con exposición Norte y Sur es facilmente detectable, debido a que los sitios de muestreo ubicados en laderas con exposición Norte tenían una mayor producción de piñas, área basal y altas densidades (ver Suzán y Gonzales 1984).

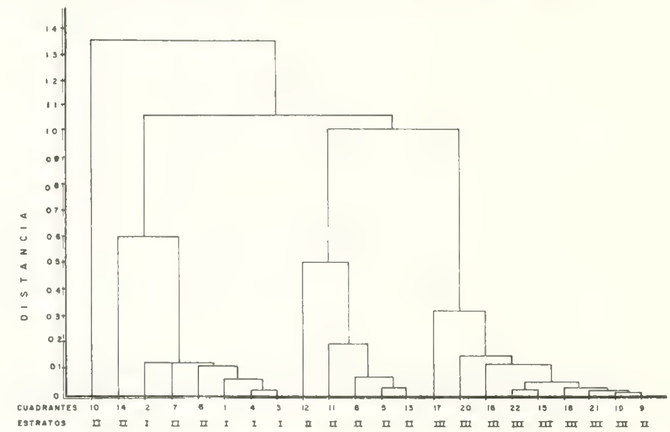

Figura 1.- Dendrograma resultante del análisis de cúmulos para cuadrantes del Cañon del Soldado.

-Para la colecta de semillas se seleccionaron 4 arboles de cada localidad que presentaban vigor y gran tamaño. Las características morfologicas de las piñas, así como el numero de semillas por piña se encuentran en el cuadro 4, donde de 110 conos analizados se tenía un promedio de 50.78 semillas por piña, y un peso de 101.4 gr por piña.
Al realizar un Análisis de Componentes Principales, encontramos que unicamente existe una alta correlacion entre el numero de semillas y su peso por piña, ocasionando que ambas variables conformen el primer componente y expliquen el 4?% de la variación. El segundo componente expresa la morfología del cono, y el tercero su peso. Estos componentes pueden ser utilizados para discriminar individuos y localidades, así como para ordenar y clasificar árboles semilleros.

Los ensayos iniciales de germinacion se realizaron en Febrero de 1986, y el primer experimento consistió de un diseño factorial con 3 niveles de sombra, 12 arboles y 3 repeticiones de lotes de 10 semillas cada una.
En el ANDEVA se encontraron diferencias entre padres, sombras y una pequeña interaccion. En el cuadro 4, tenemos un resumen de los resultados, donde se ve que

Cuadro 3.- Análisis de Componentes Principales de los datos de los conos.

ESTADISTICAS SIMPLES					
N=110	LARGO CONO	ANCHO CONO	NUMERO SEMILLAS	PESO CONO	PESO SEMILLAS.
MEDIA	9.93cm	5.61cm	50.78	101.4g	27.45g
DES. EST	2.12	0.93	28.1	87.1	15.48

MATRIZ DE CORRELACIONES	LARGO C	ANCHO C	NUM SEM	PESO C	PESO SEM
LARGO C	1	0.264	0.237	0.244	0.046
ANCHO C		1	0.262	0.248	0.368
NUM SEM			1	0.923	0.354
PESO C				1	0.433
PESO SEM					1

COMPONENTES	C1	C2	C3
PROP DE LA VARIACION	0.49	0.19	0.18

EIGENVECTORES	C1	C2	C3
LARGO C	0.261	0.696	-0.521
ANCHO C	0.346	0.567	0.464
NUM SEM	0.563	-0.300	-0.265
P. SEM	0.575	-0.310	-0.219
P. C	0.401	-0.076	0.627

Cuadro 4.- Pruebas de rango multiple (Duncan) para los porcentajes de germinación . Factores árbol y sombra.

FACTOR ARBOL			FACTOR SOMBRA		
	MEDIA	ARBOL		MEDIA	SOMBRA
A	2.53	8 C.P	A	2.805	90%
A	2.20	5 C.P	B	2.25	75%
A	2.13	3 C.S	C	1.12	50%
A B	2	2 C.S	D	0.08	25%
A B	1.8	11 J.H	D	0	TESTIGO
B C	1.26	6 C.P			
C D	0.93	1 C.S			
E C D	0.86	4 C.S			
E C D	0.53	7 C.P			
E C D	0.53	12 J.H			
E D	0.4	10 J.H			
E	0.07	9 J.H			

* NOTA : Las medias con las misma letra no presentan diferencias significativas.
C.P= Colonia la Peña ; C.S.= Cañon del Soldado;
J.H= Joya de Herrera.

las semillas responden mejor a mayores sombras, siendo probable que en condiciones naturales estas necesiten un docel para la germinación y primeros estadios de crecimiento. Al mismo tiempo vemos que los árboles padre con valores más bajos de germinación corresponden a la Joya de Herrera (árboles 9,10,11,12), y los más eficientes a el Cañon del Soldado(1,2,3,4) y Colonia la Peña (5,6,7,8).
En el ensayo de estratificación y escarificacion, había diferencias significativas en el modelo y en la

Cuadro 5.- Prueba de rango múltiple (Duncan) para los porcentajes de germinación. Factor escarificación.

	MEDIA	NIVELES
A	2.2	LIJADOS
B	1.35	H2SO4
B	1.3	TESTIGO
C	0.55	GOLPE
C	0	HCL

* las medias con la misma letra no presentan diferencias significativas.

escarificacion , en tanto que en la estratificación no se encontraron . En el cuadro 5. vemos los resultados de la prueba de rango múltiple para estratificación, donde las semillas lijadas son las más eficientes. (cabe recordar que existe una fuerte interacción con un corvido que transporta semillas en el buche friccionandolas, ayudando al rompimiento de la testa).
Al analizar la vegetación de los bosques de _Pinus nelsonii_ se han detectado tres estratos verticales, uno arbóreo con un docel muy abierto, cuya altura varia entre 3 y 7 m; un estrato subarbustivo poco definido, y uno herbáceo.
En el Estrato arbóreo se encontró una dominancia de _Pinus nelsonii_, _Pinus cembroides_, _Juniperus monosperma_, _Litsea glaucescens_, _Sophora secundiflora_, y _Quercus pringleii_ entre otras.
El estrato arbustivo presentaba diferencias en densidad, y su altura oscilava entre 1.5m y 2.5m. Las especies más comunes son _Arctostaphilos pungens_ _Quercus pringleii_, _Philadelphus sp_, _Dasylirion texanum_ y _Dasilyrion logissimum_ entre otros.
En el estrato herbáceo, encontramos _Euphorbia antisyphilitica_, _Castilleja sp_ y algunas cactaceas en peligro de extinción como _Pelecyphora pseudopectinata_.
El listado florístico inicial agrupa a 97 especies, y los estudios sobre composición florística, estructura y ordenación de las comunidades se están realizando actualmente.
Con respecto a la fauna asociada, encontramos que _Pinus nelsonii_ está menos expuesto a parásitos que los demás piñoneros, pues de las 12 principales plagas, solo se ha reportado a _Leptoglossus occidentalis_ un hemóptero que se alimenta de conillos y semillas provocando su aborción. En la zona encontramos un último refugio del osos negro en el Noreste del país, el cual junto a algunos roedores consumen piñon en diversos estadios.
Finalmente se ha detectado una aparente relación mutualística con _Amphelocoma mexicana_ y _Amphelocoma ultramarina_ azulejos que consumen grandes cantidades de piñon, pero que las transportan sín dañarlas seleccionando posteriormente las que consumirán.

Cuadro 6.- Plantas utiles del Cañon del Soldado.
(Tomadas del banco de datos de Luis Hernandez)

FAMILIA	ESPECIE	USOS
AGAVACEAE.	Agave lechuguilla	1,2,4,5,6,9
	A. striata	4.8
	Dasylirion longissimum	2,9
	D. texanum	1,2
ANACARDIACEAE	Rhus aromatica	1,2,5,7,8
	Rhus pachyrrachis	5
	Rhus virens	1,3,7,9,
BIGNONIACEAE	Chilopsis linearis	6,7,8
BORRAGINACEAE	Antiphytum heliotropioides	5
CELASTRACEAE	Orthosphenia mexicana	5,10
CACTACEAE	Opuntia rastrera	7
	Pelecyphora pseudopectinata	8
COMPOSITAE	Brickellia veronicaefolia	7
	Chrysactinea mexicana	7
	Fluorencia laurifolia	6
CRUCIFERAE	Lesquerella fendleri	2
CUPRESACEAE	Juniperus monosperma	6,7,8
ERICACEAE	Arctostaphylos glaucescens	2,7
EUPHORBIACEAE	Euphorbia antisiphillitica	5,7,9,10
FAGACEAE	Quercus microphylla	6,9
KRAMERIACEAE	Krameria cystisoides	3,7
LABIATAE	Salvia ballotaeflora	1
	Teucrium cubese	7,8
LAURACEAE	Litsea glaucescens	1,7,9
LEGUMINOSAE	Acacia berlandieri	6,9,10
	Bahuinia ramosissima	7
	Sophora secundiflora	6,10
OLEACEAE	Fraxinus gregii	7,9
ONAGRACEAE	Oenothera kunthiana	7
PALMAE	Branea dulcis	2,6,9
PINACEAE	Pinus cembroides	2,6,7,9
	Pinus nelsonii	2.6.9
	Pinus pseudostrobus	6.9
RANUNCULACEAE	Clematis drummondii	7
ROSACEAE	Cowania plicata	7,8
	Lindleya mespiloides	8
	Prunus serotina	1,2.6,7,9,10
	Vauquelinia corymbosa	7
RUTACEAE	Ptelea trifoliata	2,6,7,9
SAPINDACEAE	Doconaea viscosa	5,6,7
SAXIFRAGACEAE	Fendiera linearis	6,7
SCROPHULARIACEAE	Castilleja canescens	7
VITACEAE	Parthenocissus quinquefolia.	7,9,10.

1:Bebidas; 2:Comestibles; 3:Curtientes; 4:Fibras; 5:Industriales
6:Maderables; 7:Medicinales; 8:Ornamentales; 9:Otras; 10:Toxicas.

-Al comparar el listado de la vegetacion con los de plantas utiles encontramos una riqueza en cuanto a la flora util, pues hay 40 especies en uso, dandonos casi un 50% de las plantas detectadas en la localidad, destacando por su importancia las plantas medicinales, comestibles y productoras de fibras.

CONCLUSIONES.

1.- Existe un marcado efecto de ladera en las caracteristicas de la población, por lo que no se pueden dar esquemas unicos de manejo.

2.- Las variables de crecimiento se encuentran fuertemente asociadas, a excepción de la Altura a la Base de la Copa.

3.- La productividad de los árboles de la zona es mayor que la de los de Nuevo León que reportan Flores et-al (50.78 contra 28.9 semillas por cono), y 27.4 contra 24.3 gramos de semilla por cono.

4.- La especie es resistente a plagas, debido en parte a la dureza de su testa, y aunado a su aparente producción anual de semillas la hacen apropiada para cultivarse.

5.- Los bosques de Piñoneros del área sustentan una comunidad biótica importante, y los piónes juegan un papel importante en el metabolismo del mismo, por lo que aunado a la gran cantidad de plantas útiles y en peligro de extinción debe ser considerada como área prioritaria de conservacion.

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SISTEMAS DE PRODUCCION EN ZONAS ARIDAS: EXPERIENCIA EN LATINOAMERICA[1]

Lorenzo J. Maldonado Aguirre[2]

Resumen.- El presente trabajo describe los principales Sistemas de Producción de tipo concurrente, que para efectos de esta exposición denominaremos Sistemas Agroforestales; de los cuales, los más comunes en América Latina son: El Agrosilvocultural, El Silvopastoral y el Agrosilvopastoril.

INTRODUCCION

Las zonas áridas y semiáridas se distribuyen en más de 150 países, en donde habitan cerca de 628 millones de personas; la superficie de estas regiones es superior a 54 millones de km² lo que representa el 43% de la tierra emergida; solamente en América del Sur, con una superficie de 17'805,475 km², 3'375,079 km² son considerados áridos; esta superficie equivale al 18.72% del área territorial que ocupa. Los países lantinoamericanos más afectados por condiciones de aridez son: Argentina, con un 60% de su superficie, México con el 55%, Chile con el 50%, Perú con el 20%, Bolivia 13%, Brasil 10% y Venezuela 5% (Cuadro 1).

ANTECEDENTES

Las regiones áridas de América del Sur están confinadas a una franja a lo largo de la Costa Occidental y a una área de la parte Oriental de la Cordillera de los Andes hacia la porción Sur del Continente, a latitudes que van de los 5 a los 56° de latitud sur (figura 1).

Las zonas áridas de América del Norte, se ubican en los Estados Unidos de Norteamérica y en la República Mexicana; comprende cinco grandes regiones que son: El Desierto Sonorense, Desierto Chihuahuense, Mojave, Gran Cuenca y Baja California.

CUADRO 1. Distribución de las zonas áridas de América del Sur.

PAISES	SUPERFICIE TOTAL KM²	ZONAS ARIDAS KM²	PORCENTAJE POR PAIS	PORCENTAJE AMERICA LATINA
Argentina	2 789 241	1 673 544.6	60	9.40
Bolivia	1 098 581	142 815.5	13	0.80
Brasil	8 511 965	851 196 5	10	4.78
Chile	756 945	378 472.5	50	2.12
Perú	1 285 215	257 043.0	20	1.44
Venezuela	912 050	45 602.5	5	0.25
Otros paises	408 796	24 405.1	6	0.13
Totales:	17 805 475 km²	3 373 079.7 km²	34	18.92%

LAS ZONAS ARIDAS DE LATINOAMERICA

Las tierras áridas de Latinoamérica se encuentran regionalizadas en los siguientes tipos de desierto: El Desierto Peruano, El de Atacama, Monte, Patagónico y el Desierto de México; desiertos que poseen características específicas que a continuación se resumen:

[1] Trabajo presentado en la Reunión "Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas". Tucson, Az; USA. 12-16 de Octubre 1987.

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FIGURA 1. Zonas Aridas de Sudamérica (Meigs)

Desierto Peruano. Este Desierto se localiza en el Perú en las costas y vertientes del pacífico así como en las sierras formadas por los andes, extendiéndose hacia el norte limitando con el ecuador; se distinguen varios gradientes de déficit pluviométrico, agrupándolos en el desierto costero del norte formado por la región de la sierra; los valles aluviales de la costa y las lomas costeras; y la porción superior de la vertiente occidental andina formado por las zonas alto andinas y valles interandinos; el desierto costero peruano se vuelve menos árido hacia el norte, entrando en franca ecotonia en su porción sur con el desierto de atacama. Toda el área tiene un clima medio durante el año, con pequeñas variaciones de temperatura del verano al invierno; la niebla y las altas humedades relativas son regla general en esta región.

Desierto Atacama. Es el Desierto costero más seco del mundo con una precipitación pluvial de 10 a 65 mm al año, su distribución se localiza en el extremo sur de Perú y en la porción norte de Chile, a una latitud sur que va desde los 17 a los 30°; esta caracterizado por rangos altitudinales que oscilan desde el nivel del mar hasta los 1,000 m.; en su parte oriental se encuentra una depresión longitudinal que consiste en una serie de cuencas cerradas de 40 a 80 km de ancho, estas cuencas se han formado de material de origen aluvial acarreado de los cañones de los andes; en el norte el sur es esquelético derivado de las montañas y valles; en las planicies centrales se han desarrollado suelos pobres de textura gruesa y con depósitos pedregosos. En forma general, este desierto se encuentra casi desprovisto de vegetación a excepción de las vegas y deltas de las corrientes de agua y en las laderas humedecidas durante el invierno.

Desierto Monte. Esta región se extiende desde los 24° 35' a los 44° 20' de latitud sur en la parte media de la patagonia y desde los 62° 54' de longitud oeste en la costa del atlántico hasta los 69° 50' de longitud oeste en el interior; se localiza en la zona preandina, ocupando bolsones intermontanos; la precipitación pluvial es generalmente menor de 200 mm ocurriendo durante el verano; la oscilación térmica es alta durante el invierno el cual es frío durante toda la temporada y el verano es de clima moderado; este desierto se desarrolla en depresiones, formando planicies bajas, limitadas por montañas altas; es común encontrar características fisiográficas tipificadas por depresiones arcillosas, cuencas saladas, dunas, conos aluviales, mesetas, pendientes y formaciones montañosas.

La vegetación dominante en este desierto esta formada por arbustos resinosos de la familia Zigophylaceae; los pastos perennes se localizan unicamente en los lugares más húmedos, por lo que respecta a especies arboreas ocasionalmente se encuentran en las márgenes de los ríos formando los bosques de galera.

Desierto Patágonico. El desierto de la patagonia es el único desierto costero con exposición oriental situado en el más alto rango latitudinal hacia el sur, por lo que se considera que no tiene similitud con ningún otro desierto del mundo; esta situación es debido a que las montañas andinas forman una barrera a las masas de aire húmedo del oeste y a la corriente fría de las malvinas de la costa oriental.

Se localiza a todo lo largo de la Argentina bordeando las estribaciones orientales de la cordillera andina formando un desierto costero y de estepas de más de 1,500 km de longitud, limitado por las latitudes sur de 39 a 53°; se estrecha en su parte oriental en una distancia promedio de 560 km hacia las planicies, extendiéndose al sur hasta llegar al oceano atlántico.

El clima de esta región, es el templado frío muy seco con la presencia de vientos constantes; la precipitación pluvial es de 150 a 300 mm al año con lluvias en verano; su geomorfología esta representada por extensas mesetas con una altitud de 1000 msnm, este rango altitudinal va disminuyendo paulatinamente a medida que se acerca el mar y termina en acantilado a lo largo de la costa.

Los suelos son superficiales, de textura media, asentados sobre calizas ligeramente ácidas y con la presencia de grava en la superficie, lo que evita de que a pesar de los vientos constantes la erosión eólica no sea tan avanzada.

La vegetación esta formada por especies xerofiticas, de gramíneas y de arbustos de diferentes géneros.

Por lo que respecta a las zonas áridas de México, se han diferenciado el Desierto Chihuahuense, el Sonorense y el de Baja California, que en su conjunto cubren más de 105 millones de hectáreas, lo que representa alrededor del 55% de su territorio nacional; en estos lugares se asientan más de 10 millones de habitantes con una densidad media de 11 personas por km^2, con fuertes oscilaciones, ya que en algunas regiones se cuenta con dos habitantes por km^2, mientras que en otras existen hasta 90 personas (figura 2).

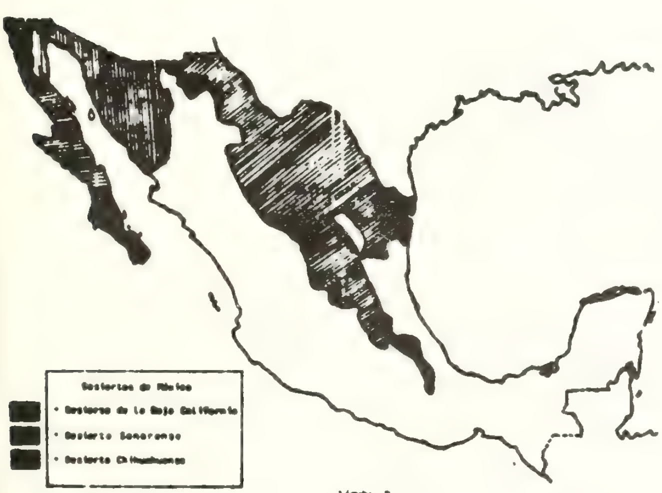

Figura 2

Desierto Chihuahuense se localiza en la parte nor central del país, entre la Sierra Madre Oriental, el Eje Neovolcánico y la Sierra Madre Occidental.

Desierto Sonorense se encuentra limitado por la Sierra Madre Occidental y la Costa del Mar de Cortés.

Desierto de Baja California, localizado en la península del mismo nombre y conocido también como Desierto de Neblinas, formado por los vientos provenientes del poniente que son enfriados por las corrientes oceánicas que bañan al litoral del océano Pacífico.

En estas regiones existe una flora muy variable que comprende más de 2,200 especies, perteneciendo por lo menos a 600 géneros de 122 familias, destacando especies con diferente valor utilitario, que van desde las leñosas, forrajeras, industriales, medicinales, ornamentales y alimentarias.

SISTEMAS DE PRODUCCION

De acuerdo a las estadísticas de la superficie de estos desiertos, a los datos dramáticos del avance de la desertificación y al aumento progresivo de la población que demanda alimentos y otros satisfactores, obliga a los organismos internacionales a desarrollar estrategias con el enfoque de sistemas de producción, que por una parte permitan la utilización, conservación y restauración de los elementos agua, suelo y biota y por otra a que estos sistemas activen los diferentes procesos del desarrollo económico.

El principal factor de deterioro de los elementos agua, suelo y biota; proceso acentuado en las condiciones ecológicas que caracterizan a los desiertos, es el aumento de actividades surgidas básicamente por el incremento de las poblaciones humanas que impacta en forma considerable a estos frágiles ecosistemas.

La necesidad de abrir nuevas áreas al cultivo destinadas a la producción de proteínas de origen vegetal en las regiones fértiles y húmedas, van dislocando la actividad pecuaria a las zonas marginales áridas y semiáridas y el aumento de ganado en estas áreas conlleva al sobrepastoreo, infiriendo como consecuencia en la regeneración natural y en la sucesión de la vegetación en sus diferentes etapas; es así como paulatinamente van desapareciendo los efectos producidos por los árboles, arbustos y especies herbáceas, reduciendo las defensas contra la erosión eólica, contra la erosión producida durante la estación de lluvias, cambios en latemperatura del suelo y una marcada desecación de los mismos.

En grandes superficies de Latinoamérica, las prácticas agrícolas tradicionales han empobrecido tanto la tierra que los rendimientos productivos disminuyen en forma drástica, perdiendo así su importancia económica, lo que obliga a la mayoría de los habitantes rurales a cambiar este sistema de producción por las actividades pecuarias.

Este simple cambio ocasiona un nuevo avance del desierto cuando no se toman las medidas necesarias para la utilización adecuada del recurso, como sería la aplicación de prácticas culturales y de

manejo más eficiente, así como utilizar especies apropiadas y más productivas.

En una óptima de gran visión en Latinoamérica se reconocen dos grandes grupos de sistemas de aprovechamiento de la tierra.

El productor tradicional, que obtiene del suelo mediante su trabajo y el de su familia - los productos que demandan su economía doméstica y el productor empresarial que se orienta a actividades de alta densidad económica como una respuesta a las condiciones del mercado externo o interno para cubrir demandas alimentarias o de materias primas para la industria.

El productor tradicional de acuerdo a la - historia, ha desarrollado en su cultura los sistemas trashumantes, que se dedican a la recolección de productos forestales principalmente, al pastoreo de bovinos, de caprinos y especies de pelo; y los sistemas sedentarios que corresponden al grupo de los cultivos de cereales, cría de ganado doméstico, plantación de frutales, etc.

El productor empresarial aunque aporta importantes beneficios económicos, el uso intensivo de los recursos en algunas circunstancias afectan al medio ambiente como contaminación del suelo por el uso excesivo de agroquímicos, cambios físicos del suelo por el uso continuo de maquinaria, sobrepastoreo en el área de pastizales, desforestación en las regiones boscosas etc.

La aridez de una región, los factores sociales, políticos y económicos, determinan que el -- "riesgo" y la "escasez de recursos" sean características típicas en la mayoría de las unidades de producción de las zonas áridas de latinoamérica; ante tal situación el productor busca la oportunidad de desarrollar una actividad o combinaciones de ellas que le permita mayor estabilidad en el - ingreso familiar; esta idiosincracia hace que los sistemas de producción sean sumamente intrincados y complejos ya que muchos agricultores en una misma parcela y en un mismo año, siembran más de un cultivo; varios cultivos son usados con el propósito de alimentar al hombre y a los animales; aprovechan la fauna silvestre como alimento, vestido - y actividades cinegéticas; la flora es utilizada - en forma de leña, de frutos silvestres, como medicinal, como industrial, o bién para alimento de ganado, etc.; por lo que estos factores son determinantes en el establecimiento de sistemas de producción del tipo concurrente, que para efectos de esta exposición denominaremos sistemas agroforestales.

Aunque estos sistemas han sido practicados - desde hace miles de años, no es hasta recientemente que se le ha dado atención científica, debido a que los ecosistemas forestales del mundo y particularmente los de América Latina, están sujetos- a una constante y creciente presión de agricultores y ganaderos de subsistencia, presión que ha - causado daños severos y en ocasiones irreversibles.

El sistema agroforestal, es un sistema de manejo que incrementa la producción de la tierra, - al combinar la producción de diferentes cultivos agrícolas con la producción de árboles y de ganado ya sea en forma simultánea o consecuencialmente y en una misma unidad de terreno, aplicando - - además prácticas de manejo que son compatibles con las prácticas culturales de la población local.

En otras palabras, es la integración de la - agricultura, ganadería y la actividad forestal.

Propiamente aplicado, los sistemas agroforestales son simultáneamente productivos y de carácter conservacionista del medio ambiente, ya que no tiene tan solo la particularidad de incrementar la provisión de alimentos, la leña y el ingreso a los agricultores o ganaderos de tierras marginadas, sino que también ayuda a detener la destrucción de - las áreas forestales.

Los sistemas agroforestales más comunes en - América Latina son: el agrosilvocultural, el silvopastoral y el agrosilvopastoril.

El sistema agrosilvocultural define como el uso consciente y deliberado del terreno para la - producción concurrente de cultivos agrícolas y - cultivos forestales; el desarrollo de este sistema debe localizarse perfectamente en base a las - costumbres de aprovechamiento más tradicionales - y que encajen en los modelos socioeconómicos existentes.

La posibilidad de plantaciones masivas de especies leñosas en terrenos que ordinariamente se consideren agrícolas, tiene como objetivo el aumento de suministro de madera además de contribuir de manera directa, a la producción de alimentos mediante los frutos o forrajes que producen estos árboles; o de manera indirecta proporcionando protección contra el viento y el sol, - reestableciendo los nutrientes del suelo y en algunos casos aumentando la fijación de nitrógeno.

Desde hace mucho tiempo, los agricultores han cultivado árboles junto a sus cultivos. Esta práctica tiene su origen en la observación pragmática de que la presencia de árboles mejora los rendimientos, o son una respuesta a la gradual desaparición de algunas especies en los bosques.

Además del aumento de la productividad, existe la ventaja de tener mayor seguridad y un mejor y más diversificado régimen alimenticio debido a la variedad de productos disponibles.

En Latinoamérica existe muy poca información sobre el sistema agrosilvícola esto es entendible si consideramos que las cantidades de lluvia son bajas y no permiten el desarrollo de cultivos tradicionales de temporal y cuando sucede es sólo en pequeñas áreas o en años de alta precipitación pluvial.

Los cultivos que suelen asociar son maíz, cebada, trigo, sorgo, frijol, yuca, etc.

Una práctica muy común en esta región es la utilización de cosechas de agua para algunos frutales o bien las mismas especies nativas de potencial económico.

El sistema silvopastoril consiste en el aprovechamiento de forrajes en las poblaciones o plantaciones forestales, utilización de especies forestales de sombra en pastizales y/o mejoradores de la fertilidad, utilización de especies forestales como fuente de alimento para el ganado y utilización de árboles frutales en pastizales.

El sistema silvopastoril es poco común en las zonas áridas de América Latina, es más frecuentemente practicado en las praderas de selvas y bosques naturales; sin embargo, el uso múltiple de árboles y arbustos para alimento y ramoneo en las regiones secas es altamente importante ya que en ellas se sustentan más de la mitad del ganado bovino existente en el mundo, más de una tercera parte de ovejas y dos terceras partes de cabras; sin embargo, la productividad es muy baja y la interacción de los factores climáticos con los sociales y económicos, llevan periódicamente a la degradación de los ecosistemas y a la pérdida de su capacidad productiva.

El continuo pastoreo ha sido la actividad más destructiva de las regiones áridas de sudamérica, propiciando una eliminación progresiva de las especies forrajeras más apetecibles por el ganado.

Por ejemplo, en las laderas costeras de Perú, el pastoreo de ganado, especialmente de cabras, disminuye el valor de forraje y decrece la regeneración natural de plántulas de árboles y arbustos.

Lo mismo sucede en Chile, donde el sobrepastoreo causado particularmente por caprinos, junto con la extracción de leña para combustible y el cultivo excesivo de cereales, han degradado la vegetación favoreciendo el predominio de especies de bajo valor alimenticio para el ganado, desapareciendo casi por completo la cubierta vegetal en extensas áreas.

En la mayor parte de los países de la América Latina se realiza una ganadería del tipo extensivo.

Una de las muestras más representativas de esta práctica extensiva, es la trashumancia del ganado que es llevado a pastorear a la cordillera andina durante la temporada de verano en el Hemisferio Sur; en Chile por ejemplo, el promedio anual de cabezas de ganado mayor llevadas a esta cordillera durante los meses de diciembre a abril es de aproximadamente 200 mil que representan alrededor del 30% del ganado chileno.

El sistema agrosilvopastoril consiste en manejar el suelo para la producción de cosechas agrícolas, animales domésticos y flora y fauna silvestres, sistema que se identifica con los anteriormente descritos, siendo su establecimiento casuístico de acuerdo a las condiciones del lugar.

En la actualidad, al analizar los sitemas de producción descritos con aterioridad, se observa que la conservación y desarrollo de los elementos Agua, Suelo y Biota en América Latina, no han podido traspasar la barrera de la incompatibilidad, debido principalmente a que en los planes de desarrollo económico no se consideran los aspectos de conservación porque los beneficios para fines contables no son tangibles. A esta situación se le debe añadir los sistemas tradicionales de producción. La carencia de tecnologías integrales y las condiciones sociales, económicas y culturales de las poblaciones rurales que dependen de estos recursos.

CONCLUSIONES Y RECOMENDACIONES

Aún cuando se detectan lagunas en el conocimiento de los sistemas de producción, sí se pueden definir y recomendar actividades que tengan como metas la utilización, conservación y restauración de los recursos Agua, Suelo y Biota; la consecusión de estas metas pueden lograrse a través de las siguientes acciones específicas:

- Intensificar las actividades relativas al inventario y evaluación de los recursos naturales en las regiones áridas y semiáridas para lograr un conocimiento más amplio de sus estructuras y funcionamientos.
- Fomentar estudios en relación a las causas y efectos de los procesos de erosión y elaborar metodologías para la recuperación de áreas erosionadas.

- Llevar a cabo estudios ecológicos en las relaciones suelo-agua-planta-animal e interpretar sus procesos con el fin de utilizar estos recursos en forma eficaz.

- Desarrollar y utilizar tecnologías para el aprovechamiento de los recursos hídricos disponibles.

- Bajo el enfoque de sistemas analizar la productividad de las zonas áridas para diseñar tecnología para un manejo integrado, permanente y productivo.

- Desarrollar tecnologías para la conservación *in situ* de los recursos genéticos de la flora y fauna silvestres.

- Desarrollo y utilización de técnicas de aprovechamiento de la energía solar, eólica y otras formas no convencionales de energía.

- Identificar e intensificar el aprovechamiento de los recursos bióticos de zonas áridas para su uso en el campo de la industria, la medicina y la artesanía, así como alimento.

- Desarrollar métodos y sistemas de predicción del clima, en particular enlo relativo a la sequía y su efecto en la producción y productividad silvoagropecuaria y de la fauna silvestre.

- Desarrollar y utilizar tecnologías orientadas a la selección de plantas y animales resistentes a la aridez y rescatar los métodos autóctonos para su posible reutilización.

- Incrementar los estudios demográficos y socioeconómicos inherentes a los ecosistemas áridos y semiáridos.

Además de estas acciones específicas, donde se engloban razones físicas, económicas y sociales; la estrategia de desarrollo para Latinoamérica debe encaminarse a establecer sistemas de producción integral que permitan en primer lugar, promover la integración horizontal de la producción (manejo agro-silvo-pastoril) y, en segundo lugar la integración vertical de los productos obtenidos, con su elaboración y comercialización (agroindustria) a fin de maximizar y optimizar el gasto de energía en cada uno de los sistemas de producción identificados en Latinoamérica.

La problemática que representa el deterioro de las comunidades vegetales, y el grado de avance de la desertificación en muchas regiones y la baja productividad, no se debe someter a una estrategia de conservación y producción a través de sistemas adecuados de aprovechamiento sino que es una "necesidad imperiosa".

Lo anterior se identifica con los principios emandados por FAO-UNESCO en 1980:

"La conservación de los recursos naturales en su más amplia expresión, se define como la utilización de la biósfera por el ser humano, de tal suerte que aporte beneficios sostenidos para las actuales generaciones, pero que mantenga su potencialidad, para satisfacer las necesidades y aspiraciones de las generaciones futuras".

Abstract.- This paper describes the most in importance Agroforestry Production Systems in Latin America; whibh are: Agrosilvocultural, Silvopastoral, & Agrosilvopastoral.

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PASTOREO SIMULADO EN TRES ETAPAS VEGETATIVAS DE *MUHLENBERGIA PORTERI*[1]

Ricardo Almeida Martínez[2] y Gary B. Donart[3]

Resumen.- Se hicieron mediciones de 19 variables a un grupo de plantas de *Muhlenbergia porteri* representando tres estados fenológicos en un primer año, y posteriormente en un segundo año para ver efecto de corte simulado. Se empleó análisis multivariado, análisis discriminante, para eliminar variables, resultando que la altura de la planta, define de mejor manera el efecto del corte al inicio del ciclo vegetativo.

INTRODUCCION

El pastoreo en su forma natural ocurre en el campo impactando a una población de plantas, las cuales en un ciclo anual generalmente se diferencian en etapas fenológicas, o etapas de crecimiento. La caracterización estructural de etapas fenológicas de una población vegetal se realiza con la medición de múltiples variables, que generalmente, por el número de datos acumulados, dificultan sus evaluaciones. Con la computación se pueden emplear metodologías que eliminan aquellas variables que ofrecen poca información, lo cual facilita la fase de análisis, algunas de estas son las metodologías estadísticas que corresponden al análisis multivariado, entre ellos el análisis discriminante (Goldstein y Dillon, 1978; Dagnalie, 1971). Otra aproximación para detectar el efecto de pastoreo son los estudios fisiológicos, considerando la reserva de carbohidratos (Donart y Cook, 1970; Miller y Donart, 1979), estas metodologías requieren de la conservación de muestras y análisis de laboratorio. Por otra parte, la simulación de pastoreo puede referirse a los niveles de utilización determinados por la fracción de forraje cortado de la planta y por la frecuencia o número de veces que ese corte se realiza; además se debe considerar efectuar los trabajos *in situ* para asemejar el proceso real. Por lo anterior se optó por una aproximación de enfoque estructural.

Las poblaciones de *Muhlenbergia porteri* Scribn. ex Beal. son de gran importancia dado que toleran altas temperaturas y sequía, también nuestran un grado de asociación mayor que otras plantas con la gobernadora (*Larrea tridentata* (DC) *Coville*). Estos son atributos muy deseables para la conservación y manejo de especies susceptibles al pastoreo, se requiere entonces, conocer los efectos de corte, pastoreo simulado, en las diferentes etapas fenológicas. El objetivo de este experimento fue determinar el impacto de corte en las etapas de crecimiento inicial, embuche y floración, realizados en 1978 y subsecuentemente en 1979, a través de mediciones en variables estructurales de *Muhlenbergia porteri*.

DESCRIPCION DEL AREA DE ESTUDIO

El lugar de estudio se encuentra en el Municipio de Santa Ana, Nuevo Mexico, EE. UU. en Parker Heights, aproximadamente 32 km al Norte de Las Cruces, con una elevación de 1450 m. Las precipitaciones en los años de estudio fueron de 40.58 y 24.56 cm en 1978 y 1979, respectivamente, siendo los rangos de temperatura para los mismos años de 12 a 41°C y 14 y 39°C. La vegetación la clasifican Donart, *et al*, (1978) como asociación de Gobernadora y Muhlenbergia de la región Chihuahuense, donde se encuentra principalmente *Larrea tridentata*, *Muhlenbergia porteri*, *Hilaria mutica*, y escasa *Bouteloua curtipendula*. Los suelos someros con caliche a profundidades de 15 a 30 cm.
La descripción del lugar corresponde a un tipo de vegetación de Matorral Inerme o Sub-inerme Parvifolio según Miranda y Hernández (1963), que representa vastas áreas del Norte de México, para fines prácticos de ubicación la parte Central Norte de México es similar al área de estudio.

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METODOLOGIA

Inicialmente se enumeraron las plantas de *Nuhlenbergia porteri* que estarían sujetas a los cortes y se etiquetaba según fuera su tratamiento. Por otra parte se colectaron 30 plantas para calcular la relación tamaño-peso y poder simular una utilización de 50%, de acuerdo a 5 clases-tamaño. Cinco clases representaban a cada uno de los tratamientos que se identifican en el Cuadro 1; ahora bien, el efecto de corte fue detectado en 1979 en etapas fenológicas coincidentes. Las 19 variables que se midieron se enlistan en el Cuadro 2, estas se repetian a tres tallos de cada planta. La información se procesó empleando análisis discriminante, el cual elimina variables que ofrecen poca información bajo dos criterios, la minimización del índice de Wilk's lambda y las distancias de *Mahalnobis* que emplea la mayor distancia entre los grupos mas similares. Ocurren varias iteraciones y se establecen los coeficientes de una función canónica estandarizada cuya dimensionalidad se representa como:

$$X = b_1 x_1 + b_2 x_2 + \ldots + b_p x_p \quad (x_1 \ldots p)$$

donde:

x = son las mediciones individuales
X = función discriminante.

Los grupos preclasificados son cotejados con los grupos que se derivan o se generan en el análisis discriminante y se ofrece un valor relativo en porciento, el cual ofrece información en el empalme de poblaciones similares.

Cuadro 1. Grupos identificados por número y tratamiento de corte de *Muhlenbergia porteri*.

Número asignado (clase)	Identificación
1	Plantas que se cortaron en crecimiento inicial en 1978.
2	Plantas que se cortaron en embuche en 1978.
3	Plantas que se cortaron en floración en 1978.
4	Cortes contínuos en 1978.

Adicionalmente a las variables consideradas para el análisis discriminante se mide la longitud de la raíz, su exclusión inicial se debe a que la representación estructural de *Muhlenbergia porteri* era referida a su parte aérea.

Cuadro 2. Nombre de variables que se iniciaron en 1978 y 1979 de *Muhlenbergia porteri* en las etapas fenológicas: crecimiento, embuche y floración.

Número de Variable	Nombre de Variable
VAR 01	Altura
VAR 02	Número de entrenudos
VAR 03	Longitud entrenudo 1
VAR 04	Longitud entrenudo 2
VAR 05	Longitud entrenudo 3
VAR 06	Número de ramas
VAR 07	Longitud rama 1
VAR 08	Longitud rama 2
VAR 09	Longitud rama 3
VAR 10	Longitud de ent. rama 1
VAR 11	Longitud de ent. rama 2
VAR 12	Longitud de ent. rama 3
VAR 13	Número ent. de rama 1
VAR 14	Número ent. de rama 2
VAR 15	Número ent. de rama 3
VAR 16	Longitud de hoja superior
VAR 17	Longitud de hoja intermedia
VAR 18	Longitud de hoja inferior
VAR 19	Porciento de tallos muertos

RESULTADOS

El impacto del pastoreo simulado por cortes a las plantas de *Muhlenbergia porteri* se pudo analizar con datos obtenidos en 1979. Se utilizó el análisis discriminante para los grupos tratados en 1978 en las etapas fenológicas de crecimiento inicial (C), embuche (E) y floración (F). En la etapa de crecimiento inicial en 1979 se detecta que la variable altura proporciona la mayor información para separar los grupos, o sea, es la variable mas discriminante. Le sigue en importancia el número de entrenudos que se puede considerar concomitante a la primera. Esas dos variables mas la longitud de la raíz se utilizaron para representar (fig. 1) *Muhlenbergia porteri* en las poblaciones sin efecto de corte, tal y como aparecen en 1978. Se observa que hay una disminución de la longitud a la raíz en la etapa de dormancia.

En las mediciones realizadas en las etapas de embuche y floración en 1979, ya no aparece la altura como la variable mas discriminante, sino las estructuras inferiores como la hoja inferior de ramas muestreadas. Eso es congruente con aceptar un efecto de corte al cambiar la altura y haciendo mas similares a las poblaciones; o sea, de similar altura.

Por lo tanto, la representación gráfica en la figura 2, solo indica un efecto parcial de la altura, en el sentido que disminuye la información ofrecida por esa variable en las otras etapas fenológicas.

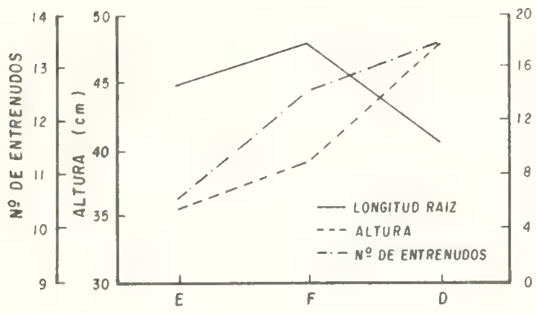

Figura 1. Mediciones de las variables mas importantes tomadas en la etapa de embuche (E), floración (F) y dormancia (D) en 1978, en *Muhlenbergia porteri.*

Sin embargo se puede apreciar que el efecto de corte en la etapa de embuche tuvo un detrimento mayor que los cortes realizados en forma contínua. Esto se puede explicar por un mecanismo de adaptación al corte realizado en la etapa inicial y subsiguientes, un corte en embuche y floración, etapas que representan estados reproductivos presentan efectos negativos, dado que sus alturas disminuyen.

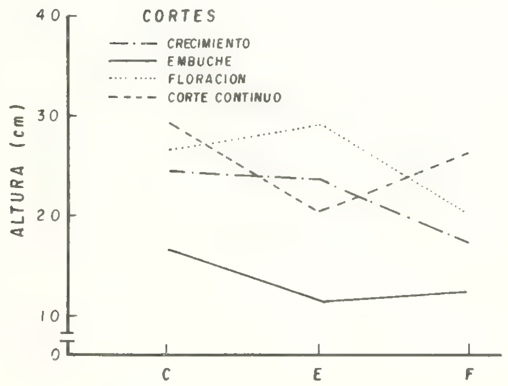

Figura 2. Medias que representan las poblaciones de *Muhlenbergia porteri* en las diferentes etapas vegetativas en 1979 según su altura.

Los resultados del análisis discriminante también proporcionan información de la sobreimposición de las poblaciones. Las mediciones de 1979 en la etapa fenológica de crecimiento inicial separaron en un 64% a los tres grupos preclasificados, según el tratamiento de corte de 1978, donde la altura resultó la variable mas discriminante; sin embargo, las mediciones de la etapa fenológica de floración de 1979 explica en un 80% la preclasificación de los cuatro grupos.

DISCUSION Y CONCLUSION

Las etapas fenológicas de crecimiento inicial, embuche y floración pueden ser representadas por poblaciones de *Muhlenbergia porteri* para determinar en forma relativa el efecto de pastoreo simulado. La dificultad de diferenciar las poblaciones y por ende el efecto de tratamiento radica en el conjunto de múltiples variables y estas no conservan consistencia al aparecer con diferente posición o importancia según sea la etapa fenológica en que se representa esa población. La altura no puede ser utilizada como única variable para detectar el efecto de corte. La preclasificación de grupos en caracterización de poblaciones biológicas ha sido mayor en el trabajo de Méndez y Rodríguez (1978) pues encuentran explicación de un 91% para su separación; o sea, poco empalme. Aunque en el caso de estudios de situaciones mas complejas para el manejo de recursos naturales, como son las clasificaciones de embalses, los valores son menores (Arredondo, Hernández, Ochoa y Ponce, 1982).

Es posible que a medida que se pueda realizar una mejor caracterización de grupos o poblaciones vegetales, se pueda explicar de mejor manera los cambios de crecimiento y también el efecto de tratamientos.

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Converting Forage to Food with Cattle on the Santa Rita Experimental Range[1]

S. Clark Martin[2]

Abstract.--Perennial grasses are the most productive forage plants on the Santa Rita but shrubs such as velvet mesquite, and annuals enhance forage quality at times. Moderate stocking and suitable rotation shedules are essential for sustained high yields.

On the Santa Rita we use cow-calf herds to convert forage to beef. Cattle are sold around November 1. Sale animals are mainly current year's calves, and cows culled for age or failure to breed. Live weight of animals sold per year ranges approximately from 4 kg/ha on the driest part of the range to 16 kg/ha in the most productive pastures.

The primary unit of production in cattle raising is the forage plant. Just as cattle covert forage to beef, plants convert soil moisture and nutrients to forage. To stay alive forage plants draw water and nutrients from the soil, grow leaves and make their own food. Range beef production is possible only because forage plants can produce more foliage than they require to survive and reproduce. Potential production is set by land and climate. How close we approach potential depends on how much moisture gets into the soil <u>and is used by forage plants</u>.

Precipitation on the Santa Rita ranges from 25 cm at 900 m elevation to 50 m at 1300 m. Summer rains (June-Sept.) account for about 60% of the annual precipitation and produce about 90% of the perennial grass forage (Culley 1943). Cool season precipitation (Nov.-Mar.) usually produces a small amount of spring growth on perennial grasses and a crop of cool season forbs 1 or 2 years in 10. Cool season precipitation also replenishes deep moisture that produces new leaves, flowers and fruits on velvet mesquite (<u>Prosopis juliflora var velutina</u>) and other leguminous shrubs in late spring.

Forages on the Santa Rita include annual and perennial grasses, annual and perennial forbs, and shrubs. Perennial forbs contribute little to total production. Yields of annuals are not reliable and they are affected little by grazing practices. Browsing on shrubs is not heavy enough to be detrimental. We manage for perennial grasses because they produce more forage and protect the soil more effectively than the other forage classes do and because they respond predictably to grazing. To achieve sustained high production of perennial grasses requires realistic stocking and appropriate grazing schedules.

Realistic stocking recognizes that frequent drought is to be expected. It strives to meet the needs of cattle, plants, and soil. For optimum production the soil needs an effective cover of plants and litter. Perennial grasses need enough growing time between bites to produce vigorous leaves and make seed. Grasses must also provide enough ungrazed litter to meet the soil's needs for cover. Herbage remaining--<u>after these needs</u>

[1]Paper presented at symposium on strategies for classification and management of native vegetation for food production in arid zones (estrategias de clasificacion y manejo de vegetacion silvestre para la produccion de alimentos en zonas aridas). [Tucson, Ariz., October 12-16, 1987].

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are met--is all we should allocate for grazing. This puts the cow last. She needs forage to meet her seasonal requirements for maintenance, reproduction, and milk flow.

Animal production is one guide to proper stocking. Mature cows on the Santa Rita weigh around 450 kg, calf crops approach 90%, and early spring calves weigh 180-225 kg by Nov. 1 These values are for good quality Hereford cattle on properly stocked range. Lower values over a period of years would indicate that animals don't get enough to eat, i.e., overstocking. Cattle that do not get enough to eat may use almost all of their intake for maintenance. Such heavy stocking obviously wastes animal productivity. Bement (1969) found that the optimum stocking rate for blue-grama (*Bouteloua gracilis*) range in Colorado lay between the rate that gave maximum gain per animal and the somewhat higher rate that gave maximum gain per hectare. Another author (Riewe 1961) reported highest economic returns on improved pasture by stocking for near-maximum gain per animal. We have not established these parameters for the Santa Rita. It is clear, however, that striving for maximum gain per hectare can result in severe livestock losses and extreme damage to vegetation and soil in years of low forage production.

Cow weights on the Santa Rita change with the amount and quality of forage. The quantity and quality of perennial grass forage is greatest during the summer growing season (Cable and Shumway 1966). Cows then can provide milk for their calves and begin to regain weight they lost earlier in the year. Cows reach peak weight in November or December, lose about 50 kg in calving or soon after, then show minor gains and losses Jan.-June (Ward 1975). Dry grass and browse provide most of the forage Nov.-Jan. Cool-season annuals and spring growth on perennial grasses may add quality to the diet Feb.-Apr.

If all of the grass is gone, cattle can subsist on leaves, flowers and fruits of mesquite with very little grass Apr.-June. However, yearlong grazing that forces cattle to live on shrubs alone in the late spring, will destroy the perennial grasses. Very sparse stands of perennial grasses in open stands of mesquite can be improved over time by rotation grazing. The Santa Rita Grazing System, a 1-herd, 3-pasture, 3-year schedule that rests each unit 2/3 of the time (Martin 1978) is probably minimal. Research and experience elsewhere indicate that plans using 1 herd and 8 pastures or more can be more effective than rotations with 3-5 pastures (Skovlin 1987, Heitschmidt 1987).

It is difficult to use forage efficiently because production varies unpredictably. Grass production in any given year may be as low as 60 or as high as 160 percent of average (Martin 1975). Another problem is that forage yield cannot be determined until the growing season is over. The grasses then are declining in quality and the period of rapid animal gains for the year is passed.

How can a rancher stay in business in the face of such unpredictable variation? One approach is to adjust animal numbers each fall to the amount of available forage. One problem is that increases or decreases in animal numbers that match forage production changes in magnitude are not feasible. Less drastic adjustments are useful, however. In making stocking adjustments, low production is a more urgent signal to reduce numbers than high production is for an increase. This is because the hazards of neglecting to reduce numbers after a dry summer are more predictable than the benefits of increasing stocking to utilize high production. If extra animals are kept in the fall to use surplus forage they should be removed from the range before the next summer growing season begins because, if the next summer brings drought, the range will be overstocked at a critical time. But, if the extra cattle are sold in May or June profit may be negligible because weight gains from November to June are usually small. It is almost certain that both cattle and range will suffer if numbers are not reduced following a drought summer. The chances of making substantial profit by increasing numbers after a good summer are not nearly so good.

A study of the effect of various stocking strategies on net sales indicated that stocking at a constant level that assumes forage production will be 90% of the long-time average produced net sales almost as high as for flexible stocking and with less risk of severe damage to the range or severe losses in animal production (Martin 1975). Constant stocking, assuming average forage production, is impractical because it results in

overstocking half of the time. Constant stocking at the 90% level results in moderate overstocking about 1 year in 3 but with severe overstocking only 1 year in 15. These degrees of overstocking can be moderated by careful culling in dry years. This is especially important when 2 or more drought summers come together.

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Opportunities for Multiple Use Values in the Encinal Oak Woodlands of North America[1]

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Abstract.--Multiple use values are described for the encinal oak woodlands of the southwestern United States and northern Mexico. Yields of wood and forage are reported, along with information on wildlife values and other multiple use opportunities. Research needs to better recognize and manage these multiple use values are outlined.

INTRODUCTION

The natural resources in the oak woodlands of North America have been exploited by people for fuelwood, fence posts, and building materials. Perhaps of equal importance, these woodlands also have multiple use values in range, watershed, and wildlife conservation. As the demands for these natural resources increase, there is increasing recognition of the necessity to implement well conceived management programs on a long-term, sustained yield basis and, importantly, in a multiple use context. The purpose of this paper is to review the state of knowledge and experience in the management of natural resources in the oak woodlands of North America.

EXTENT, DISTRIBUTION, AND CHARACTERISTICS

Descriptions of the climate, physiography, plant and animal resources, and past and present land management practices in the oak woodlands are presented below. Much of the information for these descriptive summaries was obtained from Brown (1982) who, in turn, reviewed and summarized nearly 1,000 references on the biotic communities of the southwestern United States and northern Mexico.

Dominant trees in these mild winter-relatively wet summer woodlands are evergreen oaks (*Quercus* spp.), and junipers and pinyons in varied proportions. The woodlands are composed wholly or partially of oaks at lower elevations, and of mixed oak-pine woodlands at higher elevations. Discussion in this paper is centered on the oak woodlands, also termed encinal oak woodlands, from the Spanish designation to describe evergreen woodlands that are wholly or partially of oaks.

The encinal oak woodlands are concentrated in the Sierra Madre Occidental of Mexico, from where they reach northward into southeastern Arizona, southwestern New Mexico, and Texas. In aggregate, the encinal oak woodlands cover approximately 80,500 square kilometers, although a precise delineation of this biotic community is difficult, as inconsistent criteria for classification have been employed.

Climate

Annual precipitation exceeds 400 millimeters, of which 200 millimeters fall during the growing season of May through August. Extremes in annual precipitation range from 330 to over 1,000 millimeters. Freezing temperatures are rare in the southern portions of the woodlands, but they increase to an average of almost 125 days at the northern limits.

Physiography

The encinal oak woodlands are found in the foothills, bajadas, barrancas, and sierras of the Sierra Madre Occidental and its outlying mountain ranges, and in the lower elevations of the mountain ranges in southeastern Arizona and extreme southwestern New Mexico. In elevation, the woodlaads occur between 1,200 and 2,200 meters.

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[1]Paper presented at the USA-Mexico Symposium on Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones, Tucson, Arizona, October 12-16, 1987.

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Woodland stands commonly are located along drainages, on rocky slopes, and on other thin-soiled habitats. Distinct patches of encinal woodland species often are surrounded by subtropical deciduous forests, a mosaic pattern that is attributed to variations in soil type (Goldberg 1982).

Plant Resources

A large variety of oaks are found in the encinal oak woodlands of the Sierra Madre Occidental. Chihuahua oak (Q. chihuahuensis) is commonly the first oak encountered at the lowest elevations. To the north, Mexican blue oak (Q. oblongifolia) is found at the lowest elevations. Other evergreen oaks are Emory (Q. emoryi), Q. albocincta, and Arizona white (Q. arizonica). In addition, deciduous oaks, including Q. chuchiuchupensis and Santa Clara (Q. santaclarensis), are found in intermixture.

Among the oaks in the mountainous regions of southeastern Arizona, southwestern New Mexico, and Texas are Emory, Arizona white, Mexican blue, and gray (Q. grisea). Silverleaf oak (Q. hypoleucoides) and netleaf oak (Q. rugosa) are found at the intermediate elevations.

Grass and grass-like, forb and half-shrub, and shrub species grow beneath the overstories of the encinal oak woodlands (Eyre 1980). However, while many herbaceous species increase with grazing by domestic livestock, the usual result of over-grazed encinals is the destruction of ground cover.

Animal Resources

The encinal oak woodlands are a principal habitat for the white-tailed deer (Odocoileus virginianus) and the Mexican grizzly bear (Ursus arctos). A variety of other mammals, both game and non-game, also are well represented. An assortment of non-game birds make the woodlands attractive to naturalists.

Cattle, goats, sheep, and horses graze on many rangelands in the woodlands on both a seasonal and yearlong basis.

Past and Present Land Management

The history of the encinal oak woodlands parallels that of the adjacent pinyon-juniper woodlands. However, in many locales, settlement in the encinal woodland occurred several years after the time of settlement in the pinyon-juniper woodlands. The more mountainous topography of the encinal oak woodlands, relative to the pinyon-juniper woodlands, was partially responsible for this delay.

People utilized, and continue to use, the encinal oak woodlands for fuelwood, fence posts, miscellaneous building purposes, and to produce food stuffs. Demands for these limited resources have been increasing in recent years.

Although livestock production is important in many areas, the woodlands have not been subjected to large-scale range improvement programs. Water yield improvements through vegetative management are rarely practiced. For both land management purposes, the returns do not justify the required expenditures.

Relatively little attention has been directed toward intensive land and resource management in the encinal oak woodlands. Again, the long rotation period that characterizes the trees and shrubs in these woodlands is a major reason. With increasing demands for fuelwood, as well as for other woodland-based resources, systematic management plans are now being formulated by several land management agencies.

PRODUCTION

In the following paragraphs, the encinal oak woodlands are summarized in terms of stand, stocking, and growth characteristics. Additionally, general management considerations are outlined for sylvo-pastoral production systems, a common land management strategy in the encinal oak woodlands. The importance of wildlife resources also is reviewed.

Stand, Stocking, and Growth Characteristics

Source information to describe the stand, stocking, and growth characteristics of the encinal oak woodlands is limited. However, based on limited, unpublished woodland inventories in southeastern Arizona, tree densities range from only a few, scattered trees to over 150 per hectare (Ffolliott 1985). Volumes are 2 to nearly 65 cubic meters per hectare. On an area basis, total volume is estimated to be 620 million cubic meters. Relatively small, often multiple-stemmed, irregularly formed trees typically are found in the woodlands.

Trees and shrubs grow slowly, rarely exceeding 0.25 cubic meter per hectare, which is equivalent to an annual growth rate of less than 1 percent. Growth is relatively fast throughout the early and into the middle stages of development. However, as the trees become older, natural mortality increases to the point where net growth is negligible.

Sylvo-Pastoral Management

Of particular importance in the encinal oak woodlands is sylvo-pastoral management, or more simply, range management that is practiced in ecosystems that support woody plants. That range management is inseparable from forestry on large areas of woodlands cannot be denied. It is

important that conflicts in land use between the wood production and the production of domestic livestock, if they occur, be resolved to "optimize" the production of both.

The principal species of domestic livestock raised are cattle, sheep, goats, and horses. The composition of the livestock herds in the southwestern United States differs markedly from that in northern Mexico, however. A predominance of cattle is found in the former, while a high proportion of sheep and goats, in addition to cattle, graze in the latter (Downing and Ffolliott 1983). These differences are attributed to economic and socio-cultural orientations of the two countries.

The forage resources in the encinal oak woodlands are valuable to the domestic livestock that graze these rangelands. Important nutrient constituents are satisfied through the consumption of native and introduced grasses, grass-like plants, forbs, and shrubs.

Wildlife Resources

Wildlife resources in the encinal oak woodlands have value for both consumptive and non-consumptive purposes. In terms of consumptive use, management activities are centered on native big game species and, to a lesser extent, on small mammals that are hunted. Therefore, wildlife management agencies structure their managerial strategies and action plans to obtain the optimum level of big game production, consistent with other, associated natural resource values.

Wildlife populations are difficult to quantify. Nevertheless, with defecation rates as the basis, population densities for big game and small mammals can be estimated in the region. It is estimated that deer populations range from 0.5 to 1.5 adults per 100 hectares, while elk populations are less than 1 adult per 100 hectares (Ffolliott 1985). Rabbit populations vary from 2 to 3 adults per 100 hectares. It is important to note that wildlife population densities are variable, with the estimates largely dependent upon the juxtapositions of habitats, weather patterns over the period of record, and inherent "productivity" of the populations.

Big game and small mammals furnish hunting opportunities. The hunting success, a measure of the portion of a population that is "taken" during the regulated hunting season, for big game ranges between 15 and 25 percent. For small mammals, the hunting success is more difficult to quantify, as the records are not complete.

CONSERVATION

Good conservation, also termed wise use, of the natural resources in the encinal oak woodlands is an underlying goal of the land management agencies in the southwestern United States and northern Mexico. The managerial tactics undertaken by these agencies to achieve this goal for the basic resources of vegetation, soil, water, and wildlife are described below.

Forest Resources

When properly adhered to, the conservation of forest resources in the encinal oak woodlands is based on a principle of long-term, sustained yield management. In the past, this was not always the case, however, as the forest resources were commonly "mined" to provide a variety of wood products; or, the forest resources were removed to increase the production of other natural resources, such as forage, livestock, or wildlife. Currently, management is striving to attain a balance in the growth and yield of the forest resources and, simultaneously, to maintain an ecological balance and improve the livelihood of people in the region.

A principle of multiple use of the forest resources also is stressed. Out of necessity, multiple use in the woodlands is structured in a different time frame than is found in the higher elevation, commercial montane forests. The rates of development for the natural resources in arid environments is inherently low; this means that returns from the consumptive use of the resources in a particular locale are realized after relatively long time intervals (Ffolliott 1985). Therefore, long-term "investments" are required to ensure the continuance of a proper conservation theme.

Prerequisite to the conservation of forest resources is knowledge of the character of these resources. Consequently, the United States and Mexico conduct basic inventories of their forest resources on a country-wide scale. From these inventories, baseline information is obtained on growth and yield, natural mortality, and stocking conditions of the forest resources. This baseline information, in turn, provides input to the formulation of policies and the selection of managerial tactics that are suited to the forest resources in the encinal oak woodlands.

Forage Resources and Livestock Production

Forage for livestock production has increased on many woodland sites, once the tree and shrub overstory has been removed. For example, rangelands that produced forage levels of 350 to 500 kilograms per hectare before the removal of the trees and shrubs can yield forage increases of 50 to 100 kilograms per hactare following their conversion to grassland (Ffolliott 1985). However, the question of whether the sacrifice in wood resources warrants the conversion can be answered only through an assessment of comparative values for these natural resources. It generally has been found that some combination of forage and wood will "optimize" the joint production function.

Other range rehabilitation methods carried out include broadcast seeding, fertilizer application, and the construction of fences and stock tanks to ensure more uniform distributions of the domestic livestock.

Some rangelands also can be improved through modifications of the grazing systems in use. Deferred, rotation, or other systems of grazing can increase the carrying capacity of many ranges without seriously impacting the production of wood.

All factors considered, one of the better uses of the encinal oak woodlands is to provide forage to the domestic livestock that graze these areas. Situated between the lower desert and the higher elevation, commercial montane forests, these ranges can hold the key to balancing domestic livestock numbers and forage resources in the region (Springfield 1976). However, the possibilities for improving these ranges within the framework of achieving multiple benefits from the land have not been fully explored.

Soil Conservation

With the exception of "historical" precipitation events in terms of excessive, intense rainfall, soil erosion is not a serious problem in the encinal oak woodlands of North America (Ffolliott 1985). When these precipitation events do take place, however, soil erosion is common, and it can occur in magnitudes that result in wide-spread damage. Much of this damage is confined to downstream urbanized areas in which development has occurred on flood plains without proper consideration of the consequences of erosion caused by water.

Little quantitative information exists to describe the rates of soil erosion in the encinal oak woodlands. However, based on observational records, the amounts of annual soil erosion are similiar to or less than the amounts that have been reported for the pinyon-juniper woodlands (Ffolliott 1985). In these latter woodlands, annual erosion can vary from a trace to 2,500 kilograms per hectare (Clary et al. 1974, Ffolliott and Thorud 1975). The higher amounts are associated with large storms with estimated return intervals of 50 to 100 years.

Accelerated soil erosion often is associated with wildfires and subsequent rainfalls of high intensity. Wildfires tend to be comparatively hot, which results in more complete combustion of the protective litter cover. To illustrate the order of magnitude, soil erosion after a wildfire can be 25 times greater than that observed before the wildlife (Ffolliott and Thorud 1975, Hibbert et al. 1974), although the impact diminishes quickly.

Various managerial guidelines are followed for the prevention and control of soil erosion. Whenever possible, roads are not constructed in or near stream channels, or on steep slopes. Once temporary roads are closed, they generally are revegetated with perennial grasses and forbs to minimize overland erosion in the future. The harvesting of wood products often is curtailed in the dry periods of the year; once the soils become saturated with rainfall, wood harvesting may be stopped to minimize environmental degradation. Grazing by domestic livestock, which can affect the infiltration of water into the soil mantle and overland erosion rates, may have to be eliminated on fragile sites.

Watershed Management

The encinal oak woodlands are not often thought of as watershed lands. However, the water relationships in these woodlands are, perhaps, more important than those of more temperate environments. Water is always in critical balance in arid ecosystems, and this balance frequently is upset by the actions of people.

Activities that are associated with watershed management programs generally can be grouped into one of three categories: activities which minimize adverse impacts to the soil and water resources, management activities that are designed to increase water yields, and restoration or rehabilitation activities that are needed to bring a watershed from a "poor, mismanaged condition" into a productive state. Of these categories, activities that minimize adverse impacts to the soil and water resources are commonly implemented watershed management programs in the encinal oak woodlands (Ffolliott 1985).

Due to the fragile character of the soil and water resources, extreme care must be exercised to protect these resources. To ensure the protection of these necessary resources, various preventative and control measures are incorporated into watershed management programs. Many of the managerial activities that minimize adverse impacts to the soil and water resources are similiar to those employed to prevent and control soil erosion.

Wildlife Resources

To ensure multiple benefits on these fragile environments, the management agencies responsible for forestry and wildlife resources in the encinal oak woodlands attempt to coordinate and, whenever possible, complement their respective programs. It is beyond the scope of this paper to review these wildlife management techniques, as implemented in the woodlands. However, to provide a framework upon which wildlife management is practiced, the following guidelines have been offered (Ffolliott 1981, Reyes Rodriguez 1983):

1. Maintenance or enhancement of the standard of living for the steadily increasing human population in the arid zones of North America requires the maximum production of food, fiber, minerals, etc. The management of wildlife resources must be, and to a large extent is, oriented toward this need.

2. Maximum yields of wildlife resources are dependent upon well-conceived, multiple resource land management programs. Therefore, land management practices that are conducive to the maximum production of wildlife resources should be, and largely are, integrated with forestry, other natural resources, and agricultural programs.

3. Optimal populations of wildlife species depend, in large part, upon the maintenance of "favorable" environmental conditions and a balance between these populations and their environment. Achieving this balance is a recognized goal of the land management agencies involved.

4. Harvesting and utilization of wildlife resources are determined by the relative species abundance and reproductive capacity in relation to existing habitats. Therefore, emphasis is placed on real or potential values, rather than on artificial values derived from custom or prejudice.

5. Wildlife management employs a variety of techniques to maintain, or otherwise modify, existing harvesting and utilization practices. Since no single method is adequate, all techniques of management are used to the degree warranted by their proven value and utility. These practices include environmental control, regulation of harvest, artificial propagation and stocking, and predator control.

6. All wildlife management practices should be based upon the findings of adequate biological research, modified, if necessary, to reflect local conditions.

PROCESSING AND UTILIZATION OF FOREST RESOURCES

Processing and utilization of forest resources in the encinal oak woodlands has been restricted largely to use for fuelwood and fence posts. Other wood products that can be made from smaller, irregular stems and capitalize on unique physical characteristics (such as fragrance and color) offer additional processing and utilizational opportunities.

Fuelwood

The trees and shrubs in the encinal oak woodlands have been utilized longer and more intensively for fuelwood than for any other wood product. In many rural localities, wood is still a principal fuel used. Heat content, ignition, and burning characteristics are among the more important fuel characteristics (Reineke 1960). Judged by these criteria, the tree and shrub species in the encinal oak woodlands make excellent fuelwood.

The volume of fuelwood that is harvested is difficult to estimate. However, a recently concluded study in Arizona provides some insight to the volume of fuelwood that is harvested. It has been estimated that, in Arizona alone, approximately 170,000 cubic meters of fuelwood are harvested annually (Ffolliott et al. 1979). Most of this harvest is obtained from the woodlands in and around the larger metropolitan areas.

Fuelwood commonly is harvested and marketed haphazardly in the arid regions of North America, with many small, independent operators working on an occasional or intermittent basis (Barger and Ffolliott 1972). Quality of the fuelwood product, and quantity sold on a stacked basis, often are questionable. The few commercial outlets have considerable difficulty in locating dependable sources of supply and in obtaining a fuelwood product of reasonably consistent quality.

Fence Posts

Some of the tree species in the encinal oak woodlands have been utilized for fence posts because of their outstanding durability. Large numbers of fence posts were cut, for local use and as commercial enterprises, during the period of settlement in the southwestern United States and northern Mexico. However, increased use of steel and preservative-treated wooden posts has severely reduced the demand for these posts.

The annual cut of tree species in the pinyon-juniper and encinal oak woodlands for fence posts in a five-state area of the southwestern United States (Arizona, Utah, Nevada, Colorado, and New Mexico) has been estimated to be nearly 300,000 posts during the late 1960's and early 1970's (Barger and Ffolliott 1972).

Charcoal

Charcoal manufacture through carbonization is an example of chemical alteration to obtain a wood product. Many of the tree species in the encinal oak woodlands are suited to the production of charcoal, although the market is not well defined.

Extraneous Chemicals

Extraneous chemicals, which include resins, oils, and tannins, occur in the wood of most tree and shrub species. These extractives account for the specific characteristics that distinguish one

wood from another and, in large part, help determine potential uses of the wood. Many of the tree and shrub species in the encinal oak woodlands contain appreciable quantities of extractives which could be processed into usable items.

Sawn Products

The tree species of the arid zones in North America have not been widely utilized for sawn products, due to their relatively small size and poor form. Railroad ties and mine timbers occasionally are cut, on a limited scale.

Potentials for Other Wood Products

Opportunities for expanding the processing and utilization of the trees and shrubs in the encinal oak woodlands depend, in large part, upon the physical and chemical properties of the woods. Work is continuing to learn more of these properties, as well as their inherent variabilities (Barger and Ffolliott 1972, Herrera Bailon 1981).

GAPS IN KNOWLEDGE

This review of the encinal oak woodlands of North America has uncovered important gaps in knowledge, including:

1. Biological - increasing tree and shrub growth rates, establishing rotation periods, etc.

2. Socio-economic - identifying the supplies and demands for wood and other multiple use products, characterizing marketing potentials, etc.

3. Administrative - specifying wood harvesting techniques, restricting land open to wood harvesting, etc.

Attention is directed toward the biological and socio-economic gaps in knowledge. The land management agencies whose jurisdiction includes the lands on which the encinal oak woodlands are found are responsibile for establishing the necessary administrative framework.

Biological Considerations

In the past, the wood resources in the encinal oak woodlands of North America have been "more mined than managed," meaning that wood products have been removed from a site without concern for "renewing" the wood resource for future use. However, as demands increase and markets expand, the wood resources of the region must be managed in accordance with coordinated, multiple use forest management plans. To help achieve this goal, the following gaps in knowledge should be filled.

The annual growth rates of the trees and shrubs in the woodlands are low, in comparison to those found in the higher elevation, commercial montane forests. However, inventory data are incompete to adequately describe these growth rates and subsequent yields over the range of sites which can be considered for forestry practices. This information is critical to formulating the silvicultural treatments that can increase growth rates for long-term, sustained yield forest management.

In the development of "sustained yield" forest management schemes, information is necessary to establish rotation periods over which the trees and shrubs are grown to "optimize" benefits. A time interval between harvesting operations must be programmed to improve the potentials to recover wood resources for consumptive use. Source data to quantify these parameters are only partially available and for only a few, selected areas.

It must be assumed that the wood resources in the encinal oak woodlands will be "more managed than mined" in the future. Therefore, it will become necessary to ensure that sufficient regeneration is attained to provide a continual flow of wood on a "sustained yield" basis. Again, the information that is required to make an assessment of regenerative potentials is incomplete.

It is known that the tree and shrub species in the woodlands are not easily regenerated naturally, and that effective artificial measures may be too costly. Therefore, it has been suggested that long-term, sustained yield forest management only be practiced on those sites that are favorable to the establishment of natural regeneration (Ffolliott et al. 1979). It is possible, however, that these latter areas may be valuable for other natural resource products or amenities. Background information, once again, is required to answer this question.

Socio-Economic Considerations

Some of the socio-economic considerations that became evident in this review are discussed below.

In response to the increasing demands for wood products from the encinal oak woodlands, investigations have been conducted to determine the levels of supplies, both present and future, of woody biomass (Bahre and Hutchinson 1984, Ffolliott et al. 1980, Frank 1982, Schnorr et al. 1982, Tolisano 1984). One conclusion of these studies has been that, while supplies of wood are apparently available in many biotic communities, demands for wood products from these communities will continue to increase and, in the future, may approach the anticipated supplies.

In terms of fuelwood, available supplies, represented by annual accretions of woody

resources, are anticipated to increase in a largely constant trend to 1995. The demands for fuelwood also are expected to continuously increase to 1995. Extending these supply and demand trends beyond 1995 suggest that fuelwood demands may exceed the available supplies toward the middle of the next century.

Many rural people in the southwestern United States and northern Mexico have a "strong" tradition in agriculture and livestock production. Unfortunately, this tradition is not always matched by an appreciation of wood production. This lack of appreciation can be a barrier to the implementation of forestry practices that, in many instances, compete for agricultural and grazing land. However, it is possible that this barrier can be removed through improved extension services and better technology transfer mechanisms to educate the people on the beneficial role of trees and shrubs.

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Strategies for Enhanced Production of Beef and Jojoba on Northern Baja California Rangelands[1]

Alvin L. Medina[2] and Jorge Sepulveda Betancourt[3]

Abstract.--An economic assessment of grazed vs nongrazed jojoa stands revealed cattle grazing significantly reduced jojoba seed than grazed areas. Vegetation removal and water catchment treatments enhanced seed production by 2 to 2.7 times over nontreated grazed areas. Total exclusion of cattle resulted in a loss of forage and beef production. Strategies for grazing stands of jojoba, based on height and canopy attributes, are proposed for the enhancement of beef, jojoba, and other rangeland resources.

INTRODUCTION

Jojoba is an economically important desert plant found throughout the Sonoran Desert and the Baja California peninsula. Seeds of wild and cultivated plants are harvested and processed into various commercial products such as lubricants, pharmaceuticals, and cosmetics. The seed meal by-product is used as food for livestock.

Jojoba is also a nutritious forage plant for wildlife and livestock (Dayton 1931, Gentry 1958, Urness and McCulloch 1973). The leaves provide a staple diet for deer during the fall and winter when other foods are least available, probably due to its high protein and moisture content. It can withstand heavy utilization for extended time before declining in numbers (Judd 1962).

In Mexico, jojoba is a vital economic resource of rural communities. Because of this importance, the Mexican government in 1976 initiated a comprehensive program of research, management, and protection of the species. Approximately 8000 ha were excluded from grazing (Araujo M. et al. 1981). Stand improvement measures, such as removal of competitive plants and water catchment developments, have been applied to some excluded areas. The effectiveness of such treatments with respect to increased production of jojoba seed and reduced livestock production has not previously been evaluated.

The objectives of this study were to (1) evaluate the economic benefits and losses from treatments of livestock exclusion, vegetation removal, and water microcatchment developments, (2) examine plant attributes of height and canopy cover associated with high seed production that could be used as guidelines for setting grazing levels, and (3) develop alternative strategies for multiple use of excluded areas.

STUDY AREA

The study area is a 550 ha exclosure located in the Valley of Ojos Negros, about 40 km east of Ensenada in Baja California, Mexico. It is part of a series of intermountain valleys of the Sierra de Juarez mountain range and has been described in detail by Sepulveda (1987). At an elevation of 850 m., the climate is mediteranean with characteristic winter rains and dry summers. Annual rainfall averages 240 mm, with a temperature range between 10°C in January to near 25°C in July.

The mixed-shrub community is characterized by *Simmondsia chinensis* as the dominant shrub species, with *Eriogonum fasiculatum*, *Ephredra californica*, *Rhus integrifolia*, *Yucca shidigera*, and *Ambrosia confertifolia* as other common species.

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Annual species such as Vulpia octoflora, Bromus rubens, and Erodium cicutarium account for nearly all of the herbaceous forage produced. Perennial grasses are uncommon, but Stipa comata, Stipa lepida and Melica imperfecta are found in protected areas.

The soils are classified as Xeropsamments of granitic origin. The upper horizon is subject to wind erosion, given its loose-friable nature. The exposure is westerly with a slope gradient of about 2°. Sandstone rock outcrops dot the landscape.

The exclosure was established in 1976 in one of the best stands of jojoba for the purpose of excluding cattle and for experimentation with jojoba stand improvement treatments. Prior to exclusion, the site was grazed by cattle during the period from October through May, after which the cattle were moved to pastures at higher elevations. Jojoba seed is harvested during late June and July.

METHODS

Four field treatments, hereafter referred to by numbers, consisted of: (1) grazed, (2) ungrazed, (3) ungrazed with vegetation removal, and (4) ungrazed with vegetation removal and water microcatchments. Treatments were performed on about 4 ha sections within the excluded area, except for the grazed treatment, which encompassed a similar size area adjacent to the exclosure. The grazed treatment consisted of cattle use during the period between October and May at an average stocking rate of 28 ha/A.U. (animal unit) for the ten years (SARH 1986). Vegetation removal consisted of selectively grubbing out all woody species except jojoba. Small water catchments were plowed on the downslope side of jojoba plants, about 1 m from the plant's center, such that treated plants were encircled on 3 sides by a soil berm about 3-5 dm high. The intent was to collect surface runoff from upslope and retain it for use by the plant.

Treatments were evaluated in terms of jojoba seed production ten years after the exclosure and treatments were performed. Fifty female plants within each treatment were randomly selected. Sample sizes were determined using running mean approach, based on fresh seed weight and tables of sample sizes (Bratcher et al. 1970). An experimental unit was defined as a single female plant. Seed of each plant was collected and sun-dried for 10 days. Wet and dry weights were recorded. Plant density within each treatment was determined by counting all plants on 5 randomly located 1000 m^2 plots. Height, largest and smallest diameter, and canopy cover of each plant were also determined.

One-way analysis of variance tests were performed to determine differences in seed production between treatments. Multiple comparisons of height and canopy attributes, and seed production were performed using Tukey test criterion ($\alpha = .05$). Economic aspects were evaluated through graphic and tabular comparison of costs and benefits of each treatment.

Tabular comparison of economic data are presented in table 1 and computed as follows. For each treatment, the mean seed production

Table 1. Adjusted benefits derived from jojoba seed production of treated areas and investment costs. Investments costs/ha (dollars) were $44.40 for fencing, $20.00 for vegetation removal, and $10.00 for water microcatchments.

Treatment	Mean seed production (kg/plant)	Mean plant density/ha	Mean seed production (kg/ha)	Adjusted benefits ($/ha)	Total costs ($/ha)
Grazed	0.023	255	5.86	0	0
Ungrazed	0.050	255	12.75	16.30	44.40
Ungrazed vegetation removal	0.069	255	17.59	25.81	64.40
Ungrazed vegetation removal, water catchment	0.087	255	22.18	35.90	74.40

(kg/plant) was determined. Then, using the mean plant density (255 plants/ha) for the entire stand as a constant multiplier, mean seed production (kg/ha) was determined. A constant value (255 plants/ha) for mean plant density was used in order to account for unequal plant densities that might have been present prior to treatment, and reduced the effect of other factors (grazing, plant competition, incidental loss due to treatment). Hence, hypothetical benefits are projected as if all treatment areas had equal density. Adjusted benefits were determined using treatment 1 (no incurred costs) as the base value, from which other treatment benefits are subtracted. This base value is given a monetary value of 2.20/kg of seed, which is a conservative market value, given the current market value of \$1.00 to \$1.35 per pound (Turner 1987). Hence, adjusted benefits reflect the monetary conversion to dollars/ha and are adjusted for \$12.90, since no investment costs were incurred to attain this benefit. Treatment costs are also expressed in dollars/ha in order that an estimate of time required to recoup investment costs may be obtained (years = total costs/adjusted benefits).

Cattle production potential was expressed in terms of total animal units potentially available, given the stocking rate for the study area of 28 ha/A.U./year. Suggested stocking rates for adjacent range sites vary from 18 to 39 ha/A.U./year and average about 28 ha/A.U./year (SARH 1986). Aguirre (1979) reported an average stocking rate of near 35 ha/A.U. and actual use of 20.8 ha/A.U. Realized beef production in dollars is based on the number of calves that could be produced times the region's average market value of \$300 per calf. A hypothetical benefit from calf production was determined by dividing the calf's market value by the stocking rate (28 ha/A.U.), to attain a base value of \$10.70/ha.

RESULTS

Jojoba seed production (dry weight) per plot was significantly different ($p<.05$) between all treatments (fig. 1). Seed production was lowest on treatment 1. Seed production from treatments 2, 3, and 4 was 120%, 200%, and 275% greater than observed on control treatment 1, respectively. Mean seed production/ha was 5.86 kg ($\sigma = 0.56$), 12.75 kg ($\sigma = 0.72$), 17.59 kg ($\sigma = 0.70$), and 22.18 kg ($\sigma = 0.69$) for treatments 1 through 4, respectively.

No significant differences in mean seed production within treatments between respective height classes were observed, except in grazed treatment 1 where mean production was less for short plants (<1.25 m) than for taller plants (1.75 m) (fig. 1). Also, no differences were observed between medium height plants (1.75 m) and taller plants in treatments 3 and 4. Sample sizes were large enough to permit comparisons between

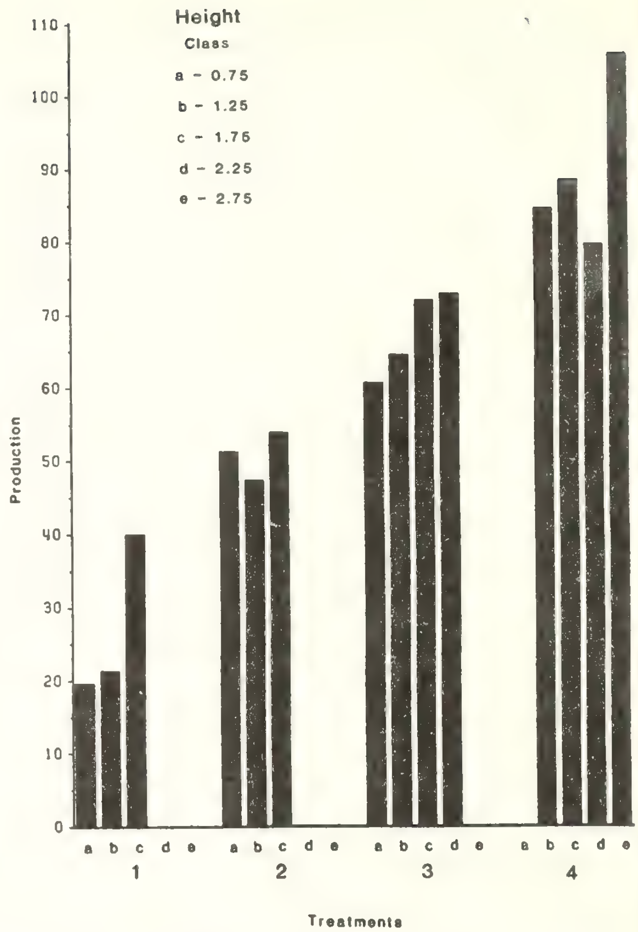

Figure 1.--Comparison of mean seed production (g) among treatments and among height classes of individual treatments. Sample sizes are indicated above respective size classes.

height classes in all cases, except for one instance in treatment 4, height class 2.75. Variances were relatively homogenous as indicated by small standard error of the mean. Significant differences in height of plants were observed between all treatments. Mean plant heights by treatment were 1.18 m ($\sigma = .04$), 1.40 m ($\sigma = .05$), 1.58 m ($\sigma = .05$), and 1.77 m ($\sigma = .05$) for treatments 1 through 4, respectively.

Similar differences were observed in mean seed production within treatments among respective canopy size classes as seen in figure 2. Plants with small canopy area (<2 m^2) of treatments 1 and 2 produced less seed than larger plants (>2.5 m^2),whereas, no differences were observed in treatments 3 and 4. Also, no overall significant differences in production were detected between medium size plants (2.5 m^2 to 3 m^2) and larger plants in treatments 2 through 4. Small sample sizes (≤ 3) were present in size class 2.5 of treatment 1, size classes 3, 3.5, and 4 of

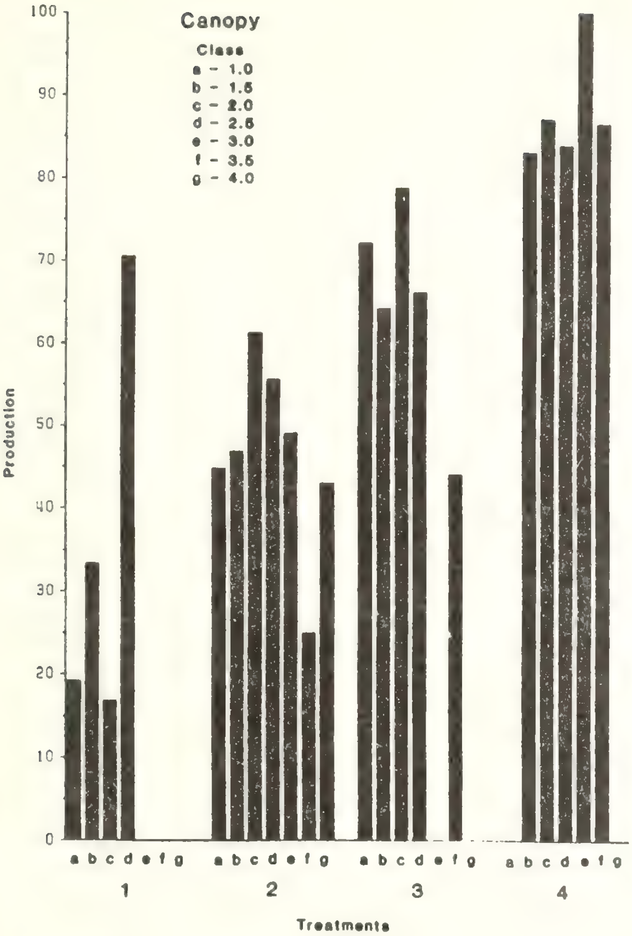

Figure 2.--Comparison of mean seed production (g) among treatments and among canopy size classes of individual treatments. Sample sizes are indicated above respective size classes.

treatment 2, and size class 3.5 of treatment 3, which prohibited comparisons between these size classes and others. However, sample sizes were adequate for all size classes of treatment 4, which proved to have the best overall treatment response.

Significant differences ($p<.05$) in canopy cover were observed between grazed and ungrazed treatments, as well as among ungrazed treatments (2-4). Mean canopy area for treatment 1 was 1.3 m² (σ = .06) compared to 1.83 m² (σ = .09), 1.90 m² (σ = .08), and 2.52 m² (σ = .08) for treatments 2 through 4, respectively. No differnces in mean canopy area were noted between treatment 2 and 3, but treatment 4 showed nearly a 37% increase in mean canopy cover over treatments 2 and 3, and about 100% greater canopy cover than treatment 1.

Mean plant density of treatment 1 (355/ha) was about 60% greater than treatment 2 (222/ha) and 67% greater than either treatments 3 or 4 (213/ha). However, respective plant size characteristics were quite different. Nearly 86% of all plants in treatment 1 were shorter than 1.5 m and 64% of all plants contained less than 1.25 m² of canopy area. In contrast, 80% of all plants in treatment 2 were between 1-2 m tall and 56% of all plants had canopy area between 1.25 and 2.25 m².

Plants from treatment 3 were similar to treatment 4 with respect to height, with about 58-60% of all plants having a mean height of 1.75 m. However, about 58% of the plants from treatment 4 had mean canopy areas between 1.75 m² and 2.75 m², compared to a similar percentage between 1.25 m² and 2.75 m² in treatment 3. Canopy area differences were more obvious due to a greater percentage of plants occupying larger size classes with respect to treatments 1 through 4.

Other differences were also noted with regard to the form or shape of the plant. Plants from treatment 1 were hedged in appearance, with flattened tops and quadrangular shape. In contrast, plants from ungrazed treatments had globular shapes.

Table 1 shows the hypothetical benefits derived from seed production from respective treatments based on tenth-year results and not on progression of earlier years. Benefits increased with each successive treatment. Treatment 4 showed nearly a 3-fold increase in benefits (dollars/ha) over treatment 1. Addition of the potential benefit from calf production ($10.70) significantly increases the potential benefits that can be realized from both seed and beef production. The minimum economic benefit derived from beef and seed production would be about $23.60/ha, based on estimates for treatment 1. This value is about the same as that derived from adjusted benefits of seed production alone from treatment 3. Since no cattle were produced from treatments 2-4, benefits realized are those for seed production only.

DISCUSSION

Jojoba responds positively to various cultural treatments, including irrigation and pruning (Yermanos 1978). In this study, jojoba responded to the reduction of plant competition, water catchments, and especially rest from livestock grazing. The higher production observed in treatment 4 is most likely due to increased soil moisture from both plant removal and water harvesting.

Despite the increased benefits derived from plant removal and water harvesting, fencing (or rest from grazing) still appeared to be the best overall range improvement. It would be very difficult for small rural communities or small ranching operations to finance the treatments unless the stands of jojoba are capable of producing reasonable quantities (as in the study

area) of jojoba seed. Hence, it is important that a complete inventory of jojoba stands be performed prior to implementation of any improvement. Nonetheless, fencing would still be the most desirable improvement so that better livestock distribution and utilization of forage can be achieved.

The effects of unregulated grazing on seed production were evidenced in figure 1. However, the data also revealed that not all ungrazed plants produced large amounts of seed. No significant differences among grazed height classes were observed, and relationship between canopy size and seed production was irregular. However, it is important to note that no difference in production was noted among medium size plants (1.6-1.8 m tall, 2-2.5 m^2 canopy cover) and larger, taller plants. These observations were more pronounced in treatment 4, where adequate sample sizes for each size class were present. Since treatment 4 had the greatest plant response which resulted in improved range conditions, the plant attributes exhibited therein are those from which management goals can be derived. This means that this medium size class of treatment 4 could be used as an index of the desirable plant size that will yield high seed production. Larger plants could be used as supplemental forage for cattle and sustained high seed production. Cattle could be used as a management tool to attain or maintain the desired plant size, given that cattle grazing would not adversely affect seed production. No detrimental effects from moderate use by cattle of jojoba plants have been reported. Most of the work with jojoba has been in regard to cultivated plants and little with wild populations. Pruning of cultivated plants is a commom practice (Yermanos and Gonzales 1976, Yermanos 1978, Scarlet 1978) and is thought to stimulate axillary growth of buds. When the terminal bud of a woody branch is removed or killed, a hormone disruption occurs causing one or more of the lower buds to develop into elongating shoots (Crawley 1983). This response could result in an increased number of stems, which could enhance the probabilities of greater floral buds. Furthermore, browsed shrubs have been shown to increase production of new stems (Ellison 1960), while in others, the growth stimulus required herbivory (Berg and Plumb 1971). Jojoba is believed to respond in similar manner to herbivory.

The economic data provided serve also as an index of valuation of jojoba rangelands. It is presented here to demonstrate potential benefits and losses on similar sites. We do not advocate that unstocked areas be restocked with livestock. Quite contrary, without the use of the excluded area, it would not have been possible to make such assessments. The usefulness of this economic index is to assist range administrators in making better decisions regarding multiple use of such rangelands, at least with respect to treatment 1. The economic assessment also aids in planning for future range improvements. The initial investment for any improvement can easily be recouped within less than ten years.

It is recommended that any system/method of livestock grazing that provides rest from grazing be used as an initial means of enhancing total rangeland productivity. A rest-rotation system might work well in a situation where a range of plant sizes is present, keying in on the size enhancement of the smaller plants. Pastures could be designed so as to encompass plants of similar size classes. Here, pastures with small plants could be rested for longer periods and used less intensely than pastures of very tall plants. In addition to fencing and a livestock grazing scheme, reseeding of impoverished ranges with perennial forage grasses is advocated. Providing additional forage might aid in reducing grazing pressure on jojoba plants, especially during critical periods of reproduction. At present there is a general lack of desirable forage plants available for cattle. The additional forage will also aid in reducing soil erosion and provide food for small wildlife species. It is furthur recommended that jojoba rangelands be grazed primarily between the period of seed maturation or harvesting and the initiation of the flowering period. It is uncertain whether cattle consume significant amounts of seed, but such use thereof has been reported (Gentry 1958).

The recommended season of use for the study area is during the fall and early winter months. Jojoba responds to winter precipitation, and initiates flower production in late winter-early spring. Seeds mature during August and September (Parra Hake and Sepulveda 1981). In areas of southern Baja California that receive summer precipitation, seeds mature during April and May. Hence, seasons of use vary for different areas, subject to local precipitation patterns. In some areas the season of nonuse may coincide with cattle utilization of summer pastures in the mountains, as was the case here.

Recommended utilization levels are also subject to the particular management objectives for the area. If high yields of seed and overall enhancement of plant size are formost, then grazing of jojoba plants should probably be light, subject to the structural composition of the stands. A moderate (about 40-50% of current annual growth, USDA Forest Service 1979) utilization rate is about the most that could be allowed in most situations, given good range conditions, and still manage for high seed production. The stocking rate of the grazed treatment was much too high as was evidenced by the stunted growth form of jojoba plants. A light level of about 10% as suggested by Roundy et al. (1985) may be more appropriate given the preliminary results of this study. In some instances, jojoba stands may require extended rest periods.

CONCLUSIONS

Livestock exclusion in combination with vegetation removal and water harvesting via microcatchments resulted in significant increases in jojoba seed production as well as improved

range conditions, as demonstrated by increased plant size. The economic analysis of potential benefits revealed that greater benefits might be realized under a multiple-use concept of seed production and cattle grazing. However, the most important objective was to provide for the betterment of jojoba plants, which when achieved could result in higher productivity from the land.

Ten years of rest from grazing resulted in about 25% increased growth in height and 41% increased canopy size. Hence, overgrazed pastures should be rested and utilized very lightly in order to enhance range conditions. Range conditions could be improved through better livestock management methods that provide for the betterment of range plants.

The results presented here are based on a preliminary study and are subject to change in light of new information. Additional research is needed to find suitable plant attributes that lend themselves as guides for grazing management as well as for enhanced seed production.

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An Analysis of Runoff and Sediment Yield from Natural Rainfall Plots in the Chihuahuan Desert[1]

Susan B. Bolin and Tim J. Ward[2]

Abstract.— Runoff and sediment yields from small natural rainfall plots in the Chihuahuan Desert were analyzed. No significant differences were found for runoff or sediment yield between plots with shrubs and plots without shrubs. It is hypothesized that any differences caused by cover were not detected because of the low energy levels of the natural rain events. These findings imply that management decisions for vegetation manipulation should include information from high energy rainfall events.

INTRODUCTION

This paper examines 17 rainfall-runoff events from four natural rainfall plots in southern New Mexico. The are nine plots located at the Jornada Long Term Ecological Research (LTER) site north of Las Cruces, New Mexico. Five plots have been treated with chlordane to remove termites and four are located on areas without the chlordane treatment. The plots (2m X 2m) were set up to represent shrub and intershrub areas. The common shrub in the area is creosote (Larrea tridentata). The shrubs are approximately centered in the plots. The intershrub plots have no creosote and very little perennial cover.

Similarities and differences between plot responses to rainfall events were investigated, and the findings are related to plot and rainfall differences. Only the plots without the chlordane treatment will be discussed because the intent is to assess rainfall-runoff and sediment yield in a natural setting.

Numerous statistical tests and comparisons were conducted on the data. The SAS package on the New Mexico State University IBM 3081D mainframe was used to summarize and analyze the data. The data were provided from an on-going LTER project at the Jornada (W.G. Whitford, Dept. of Biology, New Mexico State University, unpublished data).

[1]Paper presented at the USA-Mexico symposium on strategies for classification and management of native vegetation for food production in arid zones, [Tucson, Arizona, Oct.12-16, 1987].

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GENERAL SITE DESCRIPTION

The Jornada LTER site (fig. 1) is located in the Chihuahuan Desert on the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico. Distinct vegetation zones occur as one descends from the mountain shrubland (1501 m) to the grassland playas at the lower elevations (1318 m). The natural rainfall plots are located on a bajada in a creosote shrub zone. Average annual precipitation is 23 cm but Class A pan evaporation is about ten times higher.

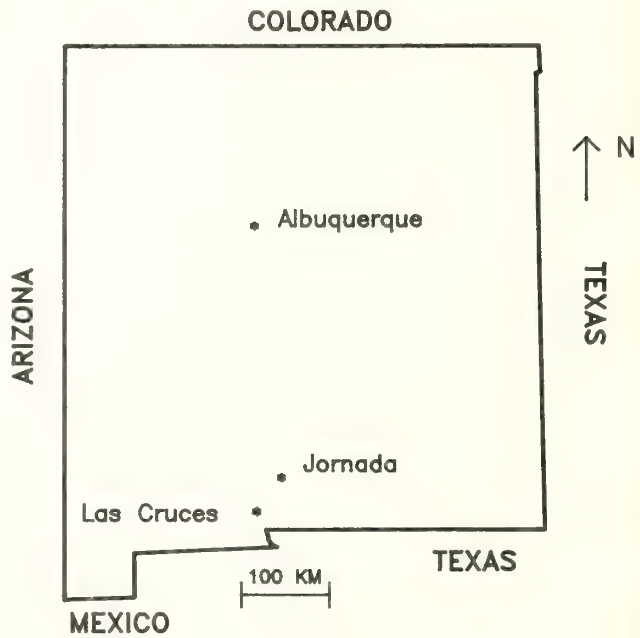

Figure 1.— Map of New Mexico showing the location of the Jornada LTER site.

Rainfall is spatially and temporally variable with 52% of the rainfall occurring between July 1 and September 30. June is the warmest month with an average maximum temperature of 36 degrees C. The maximum average temperature in January, the coolest month, is 13 degrees C (Wierenga et al. 1985).

Plot Description

Two of the plots analyzed here were installed in late 1982 with the other two plots installed about a year later. Plots are approximately 4 square meters. Slopes on three of the plots are about 2.5%. One plot, C1 (Control 1) is slightly steeper with a slope of approximately 5%. Two of the plots have a creosote bush located in the center of the plots and two plots have little to no perennial cover (table 1). There are weighing bucket and tipping bucket rain gages at the site. Records from the weighing gage were collected through July 1985 until the gage needed repair. From August 1985 to the present, the tipping bucket gage was used.

A vertical steel frame which extends 5 to 10 cm above the soil surface forms three sides of a plot. The fourth side has flashing along it at ground level so that runoff from the plot can flow into a PVC trough which channels water and sediment into a large collection tank.

An attempt is made to examine the plots after every rain (but no more frequently than once every 24 hours) to determine if runoff occurred. Because of the difficulty of always knowing when a runoff-producing storm has occurred and of having personnel available to check, some samples from the collection tank represent more than one rain event. Sometimes more than one storm occurs within 24 hours. The collected data of interest is the total volume of runoff and the concentration of suspended sediment in the runoff. Total volume is the amount of water found in the calibrated collection tank. Suspended sediment is measured by filtering a sample of runoff water after it has been agitated in the collection tank. Sediment yield is calculated as the sediment concentration times the runoff volume divided by the total runoff area.

Table 1.—Plot characteristics[1]. (Canopy cover is computed separately from the other categories. Rock includes gravel).

Plot	Perennial Shrubs %	Grasses and Forbs %	Litter %	Rock %	Bare Ground %
C1	77.2	7.8	3.5	23.2	65.5
C2	42.8	3.0	1.3	34.0	61.7
C3	10.0	11.2	2.5	12.8	74.9
C4	0.0	1.8	0.6	25.3	72.3

[1] Plots C1 and C2 have creosote bushes.

ANALYSIS

Data analyzed in this paper were selected based on two criteria. First, all four plots produced runoff during a collection period, and second, no information was missing. Seventeen collection dates met these criteria. There were more collection dates that had runoff produced on all plots, but after exceptionally large, intense rains, some of the plot collection tanks overflowed when runoff from the surrounding watershed entered the tanks. These data could not be used. However, this problem has been solved so that in the future we should not lose data from extreme (and interesting) events.

All of the collection periods analyzed were between June and November with 12 of the records in August, September, and October. There are two records from 1983, six from 1984, six from 1985 and three from 1986. Precipitation occurs between December and April at the site, but typically little to no runoff is generated.

The median number of events per collection period is four. The average amount of rain that fell in each collection period is 22.8 mm. The average intensity of events for a collection period is 7.02 mm/hr. Some storms did have much higher short-term intensities. The highest intensity within a storm for this data set is 43.81 mm/hr for eight minutes.

The initial analysis separated the data into two sets, plots with creosote and plots without creosote. All data were log transformed before analysis to satisfy the normality requirements of statistical tests. Table 2 lists means and standard deviations for each plot. Surprisingly, no significant differences in runoff or sediment yield were detected between plots with creosote and plots without creosote.

Inspection of the data for individual collection periods suggests that under some conditions, the plots did respond differently to rainfall events. This was investigated statistically by sorting the data by factors that seemed influential. The main factors seemed to be total energy received by the plot between collection periods and the antecedent soil moisture condition (table 3).

The energy equation developed by Wischmeier and Smith (1958) was used to calculate rainfall energy. The total energy was then converted to kilojoules per hectare (1 J/ha = 1 kN-m/ha = 6715.1 foot-tons/acre). The sample was divided into two parts, periods with total energy greater than 5000 kJ/ha and periods with energy less than 5000 kJ/ha. Then, the data were re-examined. A

t-test test indicated that runoff, sediment yield, and standardized sediment yield (sediment yield divided by runoff) were significantly greater ($p < .05$) for the high energy subset.

Antecedent soil moisture condition was also investigated. Again, the sample was divided into two sets. The dividing factor was whether it was more than three days since the previous collection period at the time of collection. Standardized sediment yield was significantly different ($p = 0.05$) for the two antecedent conditions with more sediment being produced from the dry set. The ratio of runoff to precipitation was significant at ($p = 0.09$) with more precipitation appearing as runoff with a wet antecedent soil moisture condition, which would be expected.

Even when the data were examined in two subsets, no significant differences could be found between the plots in terms of runoff and sediment yield. In contrast, rainfall simulation studies on the Jornada have shown significant differences between plots based on cover. Elkins (1983) did rainfall simulations at an average intensity of 125 mm/hour on a creosote area near the natural plots. Creosote cover decreased sediment yields from the plots and runoff was higher from plots with less vegetation. One important difference between Elkins' simulation plots and the natural plots analyzed here is that his plots were one square meter which made the creosote bush cover much higher per unit area.

Bach (1984) simulated rainfall with an average intensity of 90 mm/hr on three different vegetation zones on the Jornada, again using one square meter plots. The upper zone has a average plot slope of 4.2% and was characterized by black grama grass (Bouteloua eripoda). The middle zone was characterized by snakeweed (Xanthocephalum sarothrae), with slopes averaging 2.9%. The lower zone consisted mostly of burro grass (Scleropogon brevifolius) and had a mean plot slope of 2.4%.

Table 2.--Average runoff, ratio of runoff to precipitation(RO/PR), and sediment yield (SY) by plot (Standard deviation in parenthesis).

Plot[1]	N	Runoff(mm)	RO/PR	SY (kg/ha)
C1	17	3.22 (6.95)	0.10 (0.11)	45.3 (84.7)
C2	17	3.85 (7.67)	0.14 (0.12)	48.5 (108.6)
C3	17	4.25 (11.28)	0.13 (0.18)	59.5 (165.2)
C4	17	4.61 (6.87)	0.20 (0.16)	101.5 (223.7)

[1] Plots C1 and C2 have creosote bushes. Plots C3 and C4 do not have creosote bushes.

Table 3.--Pearson's correlation coefficients between runoff, sediment yield and physical characteristics of the plots and storms.[1]

	RO/PR	SY	RSY	Cancov	Rock	Energy	Days
Runoff	0.86	0.62	-0.19	-0.02	0.17	0.56	0.19
RO/PR		0.39	-0.34	-0.03	0.19	0.16	-0.13
SY			0.65	0.03	0.09	0.64	0.43
RSY				0.07	-0.05	0.25	0.32
Cancov					-0.35	-	-
Rock						-	-
Energy							0.45

1 RO/PR is runoff/precipitation; SY is sediment yield; RSY is sediment yield/ runoff; Cancov is percent canopy cover; Rock is percent cover of rock and gravel; Energy is total storm energy; Days is number of days since previous collection period.

2 Values greater than 0.23 are significant at $p < 0.05$.

She found sediment yield to be significantly greater from plots with less vegetation and to be significantly related to bare ground, rainfall rate, and runoff rate.

Figure 2 shows the differences between sediment yield for the natural rainfall data and the simulator data as they relate to energy levels. Simulator sediment yields have been adjusted to account for the lower energy per intensity supplied by the rainfall simulator. The energy supplied from the natural rainfall events does not approach the levels applied by the rainfall simulator. Sediment yields seem to increase with increasing energy levels, up to a point and then level off. A similar relationship (Bolin and Ward 1986) was found when the chlordane treated and untreated plots were analyzed together and compared to Elkins' and Bach's data.

DISCUSSION

Other studies of natural rainfall plots have also found that differences are difficult to detect between plots in arid regions. Cordery et al. (1983) report on runoff from small (25 square meter) natural rainfall plots in western New South Wales, Australia. Systematic differences in runoff between plots were not evident despite differences in physical properties of the plots. Runoff from their plots was lower during a wet period with lush vegetation than during a dry period with sparse vegetation. They attributed this to the increased interception losses due to the denser vegetation.

Many studies in arid regions that have used rainfall simulators have shown significant

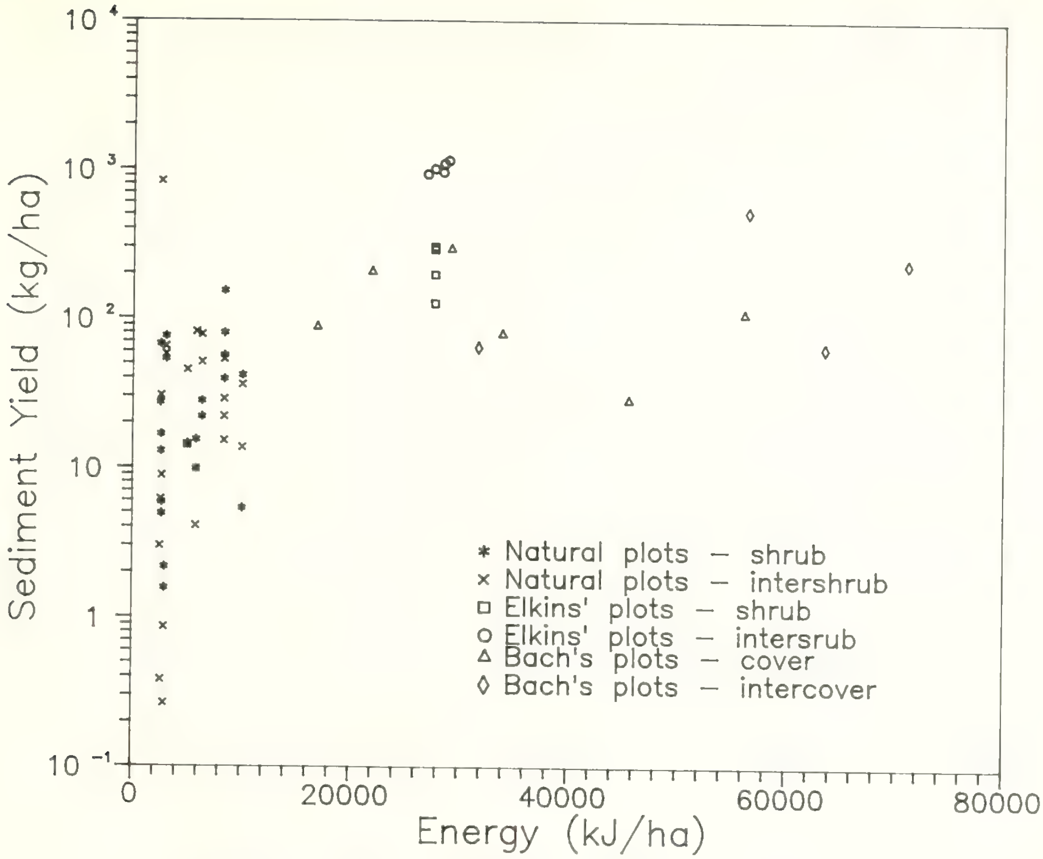

Figure 2.-- Plot of sediment yield vs. energy for the natural plots and the rainfall simulator plots.

differences in plot responses based on vegetative and soil surface conditions. Lane et al. (1987) found rock and gravel cover and canopy cover to be negatively correlated with runoff depth. Kincaid et al. (1964) also found shrub cover, grass and litter cover and gravel cover to be negatively related to runoff. In contrast, some studies (e.g. Blackburn 1975, Tromble et al. 1974) found rock cover and erosion pavement to be positively related to runoff. In the Pecos basin region of New Mexico, Smith and Leopold (1942) found that infiltration was positively correlated with vegetal density. Maybe an analysis of the energy of these different studies would help clear up the discrepancies in the role of rock cover in regards to runoff.

These studies and others that used rainfall simulators in arid and semi-arid regions with low vegetation cover have found that cover, (shrub canopy cover in particular) is an important factor in reducing runoff and erosion. Yet, two studies of runoff from natural rainfall plots in similar regions indicate that differences due to vegetation cover and rock cover are difficult to detect.

We propose the following hypothesis to explain this discrepancy. In most desert regions, cover is relatively sparse. Creosote in particular has an open canopy which allows rain to pass freely through the canopy. Perhaps when canopy and vegetation cover is below a certain minimum value, interception losses are minimal and rainfall energy is not greatly reduced. Thus energy in a given storm would have a greater effect on runoff than would shrub cover in a given area. This seems to be true at normal storm intensities as indicated by the natural rainfall plots. However, even in desert regions, rainfall simulator studies indicate clear differences in runoff and erosion due to shrub and rock cover. Perhaps there is a threshold value of energy after which if all things remain the same, no further increase in yields occurs. At that point, differences in shrub and gravel cover would begin to appear in the data. Prior to this, their effects have been masked by the overriding role of energy.

At high energy levels, runoff and sediment yield is less affected by the energy variation and more dependent on vegetative and soil characteristics. This may help explain why statistical differences were not found between plots with different vegetation and soil features from the natural rainfall plots. Energy level is a primary factor in determining yields. At lower energies, in a sparsely vegetated area like the Jornada, the role of energy predominates in determining runoff

and sediment yield. At higher energy levels a threshold is reached in terms of additional yield from energy increases alone. At that point, differences in yield show up as a function of vegetation cover and physical properties of the soil surface.

The natural rainfall plots at the Jornada are an ongoing experiment. We feel that we have solved the problem of overflowing collection tanks from extreme storms. A combination of rainfall simulator studies at lower intensities and successful collection of data from extreme storms should shed some light on this issue.

ACKNOWLEDGEMENTS.This paper was based on research from the Jornada LTER project funded by the U.S. National Science Foundation, Grant #BSR-811466. Many individuals have contributed to the collection of the data and discussion of ideas presented in the paper. In particular, we would like to thank John Anderson, Steve Van Vactor and Steve Wondzell.

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PROPUESTA METODOLOGICA PARA DETERMINAR LA RELACION AREA-SIEMBRA-ESCURRIMIENTO EN CULTIVOS DE TEMPORAL[1]

José Villanueva Diaz[2], Ignacio Sanchez Cohen[3], y Hugo A. Velasco Molina[4]

Resumen.-- Se propone un modelo matemático para el aprovechamiento de lluvia "insitu" en la producción de cultivos en zonas áridas y semiáridas. El modelo al integrar diversos factores del clima, suelo y planta, deriva en una relación área siembra-escurrimiento, con lo cual se satisface teoricamente los requerimientos hídricos del cultivo.

INTRODUCCION

Una extensa superficie de México se encuentra en condiciones de aridez, lo cual represente según diversos criterios del 50 al 70% de la superficie total del país. En estos lugares debido a la baja disponibilidad de agua para irrigación se practica basicamente una agricultura de temporal, originando con ello pérdidas casi continuas de los cultivos, ya que los requerimientos hídricos de especies como maíz y frijol dificilmente llegan a satisfacer con la precipitación registrada, la que además de ser mínima presenta el inconveniente de alietoridad en su distribución; aunado a esto, anualmente se incrementan en diverso grado las áreas con problemas de erosión y que entre ctras causas es debido al manejo inadecuado del agua de lluvia.

Una alternativa de obtener producción en zonas con deficiente precipitación pluvial, consiste en hacer un uso óptimo e integral del recurso agua suelo, de tal manera que mediante el uso de técnicas de cosecha de agua de lluvia "insitu" y de conservación de suelos, se logre aprovechar los escurrimientos superficiales y propiciar el desarrollo de cultivos en un sitio de almacenamiento de humedad, mediante una relación área siembra, escurrimiento.

El potencial benéfico de la técnica de cosecha de agua se deriva al considerar que un mílimetro de precipitación corresponde a un litro de agua por metro cuadrado, de esto se concluye que de una pequeña área con suficiente escurrimiento se puede colectar un relativo gran volumen de agua, con lo cual se puede minimisar el déficit hídrico de los cultivos. Con base a lo anterior este estudio se propone los siguientes objetivos:

1.- Definir un modelo matemático para delimitar una relación teórica área siembra, escurrimiento para el establecimiento de cultivos, mediante la técnica de cosecha de agua de lluvia "insitu"
2.- Delinear una metodología para la obtención de parámetros que involucra el modelo.

LITERATURA REVISADA

Cosecha de agua usando la superficie topográfica es el proceso de colectar y almacenar o cosechar la precipitación de un área que ha sido tratada para incrementar el escurrimiento de la misma (Cluff and Dutt 1966).

El uso de métodos superficiales de cosecha de agua no es una práctica nueva, pues data de hace aproximadamente 4000 años en algunas de las civilizaciones de Bronce. Esos agricultores clareaban las laderas de los cerros de roca y grava y de esta manera incrementaban los escurrimientos. De igual manera cabavan diques en contorno en las laderas para colectar el agua y

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[1] Trabajo presentado durante la reunión sobre estrategias de clasificación y manejo de vegetación silvestre para la producción de alimentos en zonas áridas (Arizona State University, 12-16 octubre, 1987).

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conducirla hacia las áreas de cultivo ubicadas en las partes bajas. Aun cuando esta agricultura de escurrimientos tuvo muchas fallas, estas civilizaciones lograron producir hasta con 100 mm de precipitación media anual (Evenari, Shanan y Tadmor 1982).

En la actualidad el uso de escurrimientos a través de sistemas de captación de agua de lluvia para obtener cosechas en zonas bajo condiciones pluviales deficientes vuelve a surgir como una alternativa de producción. Un sistema de captación de agua de lluvia consiste basicamente de dos partes: a) Area de escurrimiento, la cual tiene como función colectar el agua de lluvia y llevarla hasta b) Area de almacenamiento. Al aplicar ésta técnica insitu a la agricultura se ha dado origen a las denominadas microcuencas de captación de agua de lluvia; su tamaño depende fundamentalmente de cuatro factores: Magnitud de lluvia, capacidad de retención de humedad del suelo, coeficiente de escurrimiento y necesidades de agua del cultivo (Anaya, Tovar y Macias, 1976; Smith 1978). Como es poco probable que se de las mejores condiciones para la producción del cultivo (debido a la probabilidad de lluvia en cuanto a frecuencia, cantidad y distribución) la tolerancia del cultivo a la sequía es otro factor a considerar (Smith 1978).

La efectividad de las prácticas de conservación de humedad, mediante el control de escurrimientos y cosecha de agua para evitar daños por sequía, requiere no solamente aumentar el almacenamiento del agua en el suelo, sino también de condiciones de suelo que favorezcan un sistema de raíces profundo, amplio y denso que permita remover considerables cantidades de humedad para abastecer las demandas de agua del cultivo, durante los períodos prolongados en que no hay recargos de humedad en el suelo (Villarreal, Stolzy y Letey 1971).

Un sistema de concentración de agua se puede realizar usando bordos al contorno o terrazas de banco a nivel donde un área de varios metros servirá como área de escurrimiento y una segunda, pendiente abajo como área de cultivo donde será retenida el agua. La relación de las dos áreas y la relación lluvia-escurrimiento determinará la cantidad de agua que se hará disponible para el uso del cultivo. Para realizar el análisis del diseño de un sistema de bordo al contorno (Smith 1978) derivó un modelo basado en el diagrama esquemático de la Figura 1.

Donde:
Aw= Area de escurrimiento
Ac= Area de cultivo
PP= Precipitación (mm)
R= Retención de humedad en el área de escurrimiento (mm)
Q= Escurrimiento hacia el área de cultivo (mm).
PS= Profundidad de suelo (mm)
HS= Contenido de humedad del suelo, % en base volumen.
HS_1= Contenido de humedad antes de la lluvia
HS_2= Contenido de humedad después de la lluvia
HS_3= Contenido de humedad entre lluvias
ET= Evapotranspiración diaria (mm)
D= Lámina de agua aplicada a el área de cultivo (mm)
n= Número de dias entre lluvias.

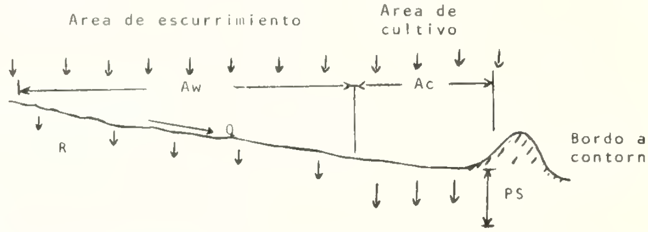

Figura 1.- Diagrama esquemático de un sistema de bordos al contorno

De la Figura 1 se obtiene lo siguiente:

$$Q=PP-R \qquad (1)$$

$$D=PP+Q\,\frac{Aw}{Ac} \qquad (2)$$

$$\text{Asimismo } D=(HS_2-HS_1)PS \qquad (3)$$

$$ET=(HS_2-HS_3)PS \qquad (4)$$

$$n=\frac{PS(HS_2-HS_3)}{ET} \qquad (5)$$

Si D=nET y PP es la precipitación promedio, entonces de la ecuación (2) se tiene que:

$$D-PP=Q\,\frac{Aw}{Ac} \qquad (6)$$

$$\frac{Aw}{Ac}=\frac{D-PP}{Q}=\frac{NET-PP}{Q}$$

$$Aw=\frac{nET-PP}{Q}=Ac \qquad (7)$$

Dándole a Ac un valor determinado para las prácticas culturales un valor de diseño Aw puede obtenerse con los datos de PP, Q y ET.

Para analizar el sistema diseñado por Smith, es necesario calcular un balance continuo de humedad para una serie de años usando varios cultivos con diferentes fechas de siembra y habitos de crecimiento radical.

Un modelo para estimar la relación área siembra escurrimiento, basado en bordeo antierosivo fué propuesto por Velasco (1983), donde los factores que tienen mayor peso en el diseño son el clima y la planta.

Para alimentar su modelo se requieren datos como:

a) Isoyeta del área de interés
b) Distancia disponible entre bordos antierosivos
c) Coeficiente de escurrimiento del área destinada a este propósito.
d) Demanda evapotranspirativa del cultivo

Integrando los factores anteriores finalmente obtuvo la siguiente ecuación.

$$L = \frac{CE\%P(PP)LT}{\%P(PP)(CE-I+Ev}$$

Donde:
CE: Coeficiente de escurrimiento (adimencional)
%: Probabilidad de precipitación (decimal)
PP: Precipitación promedio anual según isoyeta del lugar (m).
LT: Longitud total entre bordos antierosivos (m)
Ev: Uso consuntivo del cultivo (m)
L: Longitud del área de siembra: (m)

Anaya, Tovar, Macias (1976) considera que conociendo la cantidad de agua que necesita un cultivo y la cual no puede ser satisfecha por una precipitación probable esperada, se puede estimar la deficiencia de agua de ese cultivo durante su ciclo vegetativo, a través de la siguiente ecuación.

$$Ac = \frac{As+1}{CE}\ \frac{(UC-PP}{PP} \times As)$$

Donde:
Ac: Tamaño de la microcuenca
As: Area de siembra, que los agricultores tradicionalmente utilizan según el cultivo.
CE: Coeficiente de escurrimiento en el Ae
UC-PP: Total de deficiencias de agua durante el ciclo vegetativo del cultivo.
PP: Total de lluvia que cae en el tiempo que dure en desarrollarse el cultivo.

Esta tecnología supone que para cultivos en hilera una mayor equidistancia entre surcos llena los requerimientos hídricos de la especie, mientras que para cultivos tupidos, el establecimiento se puede hacer aplicando el principio de la terraza de Zingg y Hauser.

La optimización de un sistema de cosecha de agua para producción de cultivos puede llevarse a cabo mediante modelos de simulación (Asfur y Hani 1972); sin embargo la integración del modelo se tiene que hacer con pruebas de campo con lo cual se estiman las dimensiones del área de siembra y escurrimiento.

METODOLOGIA

El desarrollo del presente modelo para cosecha de agua de lluvia se deriva al realizar ciertas modificaciones a la ecuación de Velasco (1983).

Al igual que las ecuaciones presentadas por otros autores su deducción se basa al considerar que dada una superficie entre bordos antierosivos, cierta porción va a dedicarse para escurrimiento y otra para siembra. La lluvia que escurre del área de escurrimiento, mas la que cae directamente en el área de siembra, deberá satisfacer teoricamente los requerimientos hídricos del cultivo, dada una probabilidad de precipitación durante el ciclo vegetativo e involucrando asimismo ciertos parámetros fisicos del suelo. (Figura 2).

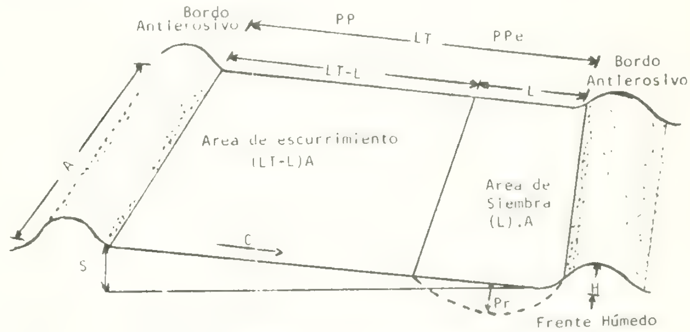

Figura 2. Diagrama esquemático para el análisis de la relación area siembra- escurrimiento.

Haciendo un análisis de la figura anterior se tendrá lo siguiente:

$$C.E.\ (PP)\ (LT-L)\ A + PPeLa = La\ (Ce-pmp)daPrN$$

Volumen de lluvia que cae en el área de escurrimiento y que es aportado a el área de siembra.	-- Volumen de lluvia que cae en el área de cultivo.	Volumen de agua requerido por el cultivo.

Simplificando términos y desarrollando la ecuación anterior

$$\frac{A\ C.E\ (PP\ (LT-L)+PPeL}{A} = \frac{La(cc-pmp)daPr\ N}{A}$$

$$C.E(PP)\ (LT-L)+PPeL=L(cc-pmp)daPrN$$

$$C.E(PP)LT-C.E(PP)L+PPeL=L(cc-pmp)daPrN$$

$$L(cc-pmp)daPrN+C.EPPL=CE(PP)LT$$

Factorisando y despejando L se obtiene finalmente la ecuación propuesta.

$$L = \frac{C.E(PP)LT}{(cc-pmp)daPrN+CE(PP)-PPe}$$

Donde:
L: Longitud del área de siembra(m)
C.E: Coeficiente de escurrimiento (Adimencional)
PP: Precipitación pluvial, según una probabilidad anual de ocurrencia y cierto periodo de retorno (m)
LT: Espaciamiento entre bordos antierosivos (m)
cc: Capacidad de campo (decimal)
pmp: Punto de marchitez permanente (decimal
da: Densidad aparente (gr/cm^3)
Pr: Profundidad del suelo o profundidad efectivas radical (m)
PPe: Precipitación efectiva (m)
N= Número de lluvias de magnitud (cc-pmp) daPr necesarias para satisfacer los requerimientos hídricos del cultivo (Adimencional).

La obtención y deducción de los diversos factores implícitos en la ecuación, son de fácil cálculo; así por ejemplo la precipitación probable se puede estimar mediante metodologías ya conocidas como el método de "distribución acumulativa" o el de gama incompleto; precipitación efectiva a través del método desarrollado por Doorenbos y Pruitt o el Blaney-Criddle y coeficiente de escurrimiento mediante lotes de escurrimiento. Por otra parte el parámetro que pudiese tener cierta dificultad en su determinación es el parámetro "N", ya que involucra diversos factores como son: a) Estación de crecimiento, b) Uso consuntivo, c) Factor de abatimiento de humedad disponible y d) Patrón de extracción de humedad disponible a una distancia igual a la profundidad efectiva radical del cultivo, o cuando el suelo es limitante a la profundidad del suelo.

La estación de crecimiento es de los parámetros de mayor importancia para evaluar los recursos agroclimatológicos de cierta región y se refiere al periodo o estación de condiciones más favorables para el desarrollo de cultivos y se basa en un modelo simple de humedad, comparando la precipitación (PP) con la evapotranspiración del cultivo (ET) o en su defecto la evaporación (Ev) obtenida de un tanque evaporímetro tipo "A"

Una estación de crecimiento se divide en varias etapas como son el inicio de la estación de crecimiento, período humedo, terminación de la estación lluviosa y terminación del período de crecimiento como se observa en la Figura 3.

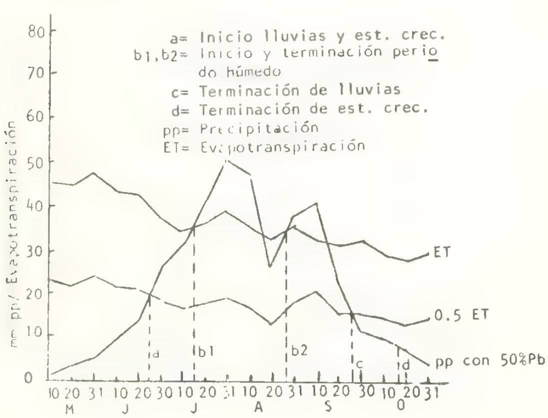

Figura 3. Estación de crecimiento típica

Desafortunadamente en las zonas áridas y semiáridas de México, la evapotranspiración supera casi siempre a la precipitación, por lo que practicamente no existe estación de crecimiento como se observa en la Figura 4.

b) El uso consuntivo es de fácil obtención, para lo cual existe diversidad de metodologías. Se sugiere que para fines de investigación se utilizen métodos directos como es el gravimétrico y para fines prácticos metodos indirectos como el de Blaney-Criddle.

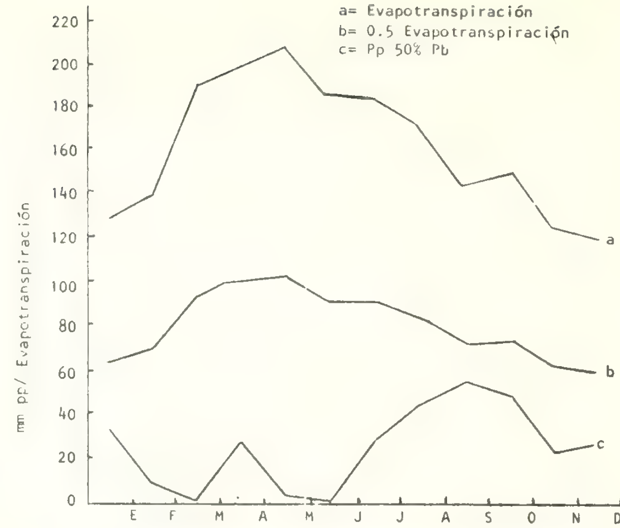

Figura 4. Estación de crecimiento en zonas áridas

c) Factor de abatimiento de humedad disponible. Esta variable se refiere al porcentaje de humedad que se va a permitir al cultivo antes de que un evento lluvioso teoricamente suceda, bajo condiciones de riego, experimentalmente se ha demostrado que el crecimiento de los cultivos disminuye poco cuando la humedad se mantiene tanto a capacidad de campo como cuando se permite que el cultivo consume el 75% de la humedad disponible y decae bruscamente al consumirse el 100%. De ahí para el cálculo de N se utilice 75% de humedad disponible.

d) Patrón de extracción de humedad disponible. Un cultivo no consume uniformemente el agua en los diversos estratos del suelo. Cuando el suelo se encuentra a capacidad de campo, casi toda el agua que el cultivo requiere va a ser absorvida del estrato superior del suelo; sin embargo conforme la humedad va disminuyendo por falta de riego o lluvia, se hará un mayor uso del agua contenido en estratos inferiores. En términos generales un patrón de extracción promedio para todos los cultivos se muestra en la Figura 5.

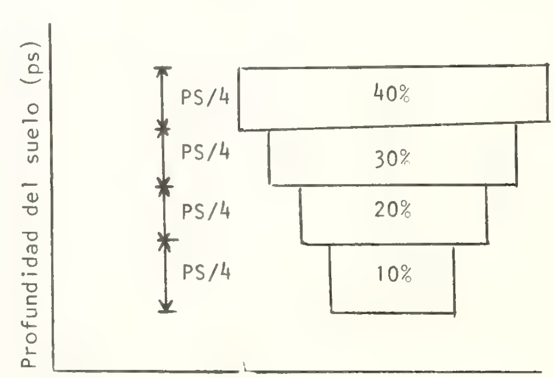

Figura 5.- Patrón de extracción de agua del suelo por las raices de las -- plantas.

Una vez determinados los cuatro anteriores parametros se está en disponibilidad de obtener el parámetro "N" y finalmente calcular la relación área siembra-escurrimiento para cierto cultivo en particular.

Con el fin de ejemplificar la tecnología anterior y con datos de suelo y clima del Area Experimental Forestal "Ex- Hacienda Vallejos" se procedió a realizar una estimación de la relación área siembra escurrimiento para una especie caducifolia.

Datos requeridos.
C.E.= 0.5 (Obtenido en lotes de escurrimiento)
PP 50% Prob. Según método de "Distribución acumulativa"

MES	E	F	M	A	M	J	J	A	S	O	N	D	Total
(mm)	10	2	11	13	39	42	25	32	49	23	4	9	248

PPe (Según método de Blaney-Criddle)

MES	E	F	M	A	M	J	J	A	S	O	N	D	Total
(mm)	9.5	2	1	12	36	39	24	30	45	22	4	9	233

LT=30 m (Calculada con una pendiente de 2%)
Especie: Durazno (Amygdalus persica L.)
Uso consuntivo: 650 mm (Según método de Blaney-Criddle).

Lámina de agua disponible según Tabla 1.
Tabla 1.-- Características físicas del suelo del Area Experimental Forestal Ex-Hacienda Vallejos.

Prof.Suelo (cm)	0-10	0-30	30-60	60-100
da(gr/cm3)	1.35	1.35	1.4	1.3
cc(%)	27	27	22	31.0
pmp(%)	14	14	10	19.0
Textura	Migajón arcilla	Migajón arcilla	Migajón	Migajón arena
Lámina de agua disponible (cm)	1.75	3.51	4.2	6.24

Una vez determinados los datos anteriores se calcula "N" según la tabla 2.

Tabla 2.-- Organización de datos para calcular"N"

Prof. 100cm/4 (cm)	Hum.disp. (H.D.)por estrato (cm)	Patrón Extrac. de hum.(%)	*Demanda evapo. diaria (cm/día/ estrato)	Tiempo de abatimiento de H.D. por estrato (días)
25	4.06	40	0.178x0.4=0.071	57
50	4.2	30	0.178x0.3=0.053	79
75	4.2	20	0.178x0.2=0.035	120
100	3.9	10	0.178x0.1=0.017	219

Demanda Evapotranspirativa diaria=

$$\frac{650\text{mm}}{365\ \text{días}} = 1.78\ \text{mm/día} = 0.178\ \text{cm/día}$$

Si se considera que el grueso de la actividad de extracción por las raíces se lleva a cabo en el primer estrato, entonces el valor de "N" estará dado por:

$$N = \frac{\text{Días del ciclo vegetativo}}{\text{Tiempo de abatimiento de humedad disponible en el primer estrato}}$$

De ahí que:

$$N = \frac{365}{57} = 6.4$$

Sustituyendo los datos en la ecuación propuesta, finalmente se calcula la relación área siembra-escurrimiento.

$$L = \frac{C.E.\ (PP)\ LT}{(cc-pmp)daPrN\ C.E\ (PP)-PPe}$$

$$L = \frac{0.5\text{x}0.248\text{x}30.0}{(0.27-0.14)1.35\text{x}1.0\text{x}6.4+0.5\text{x}0.248-0.233} = 3.7\text{m} = 4.0\text{m}.$$

De dicho análisis se obtiene una relación de 1: 7.5m, es decir de 7.5 m entre bordeo antierosivo 1m se dedicará al establecimiento del frutal y los 6.5 m restantes como escurrimiento.

RESULTADOS Y CONCLUSIONES

Integrando diversos factores del suelo,clima y planta, se obtuvo una ecuación, la cual teoricamente satisface los déficits hídricos de los cultivos a través de una relación área siembra, área escurrimiento. La veracidad de la ecuación depende de la metodología que se utilice en la obtención de cada parámetro y al respecto es deseable que algunos de ellos sean obtenidos en el área donde sea validada la ecuación como es el caso del coeficiente de escurrimiento, patrón de extracción de humedad disponible, del cultivo, uso consuntivo y factor de abatimiento de humedad disponible.

El parámetro "N" es de importancia en la estimación de la relación área-siembra escurrimiento por involucrar factores físicos del suelo y de las plantas. Teoricamente representa el número de lluvias necesarias durante el ciclo del cultivo de una magnitud tal que cada evento lluvioso eleve la humedad del suelo del área de cultivo a capacidad de campo a una profundidad igual a la profundidad efectiva radical del cultivo, cuando este ha consumido un 75% de la humedad disponible. Este valor se ha comprobado que en general constituye el límite de humedad disponible en el cual los cultivos no se ven afectados en su crecimiento, sin embargo existen ciertas especies tolerantes a sequía que pueden soportar mayores abatimientos de humedad disponible, sin que decaigan significativamente sus rendimientos. Lo anterior debe considerarse en la elección de las especies a establecer, pues es de esperarse que aquellas con mejor tolerancia a la sequía tendrían mayores posibilidades de éxito.

La parte complementaria del presente estudio, consiste en la aplicación y validación del modelo

propuesto, requiriendose su implementación bajo sitios representativos de condiciones áridas y semiáridas, con especies perennes (debido al uso de probabilidades de lluvia, los cultivos anuales pueden soportar en menor escala déficits hídricos) y tolerantes a sequía de tal manera que pueden tener mayor probabilidad de éxito bajo un sistema de cosecha de agua de lluvia "insitu".

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POTENCIAL HIDRICO DIURNO Y ANUAL DE *PINUS CEMBROIDES* Y *PINUS DISCOLOR* EN LAS SERRANIAS MERIDIONALES DE SAN LUIS POTOSI

Héctor M. Benavides Meza[2,3] y Edmundo García Moya[2]

Resumen.--El potencial hídrico (Ψw) de las especies piñoneras Pinus cembroides y P. discolor fue registrado bajo condiciones de campo durante un día de cada mes, en un año. P. cembroides presenta, por lo general, valores más bajos de Ψw que P. discolor, aunque no siempre estadísticamente significativos. Ambas especies presentan además un valor umbral de Ψw, situado para P. discolor entre -0.9 a -1.1 MPa y para P. cembroides entre -1.1 a -1.3 MPa, el cual ocasiona un cierre estomático que se refleja en el incremento del Ψw de las plantas, en las horas subsecuentes después de que se alcanzó dicho valor.

INTRODUCCION

En las zonas áridas de México existe un gran número de especies vegetales con potencial alimentario sujetas a recolección, en las cuales se observa una disminución sensible de su producción en razón del deterioro del entorno físico-biótico, lo cual pone en tela de juicio su capacidad productiva en forma sostenida. Los bosques de piñoneros son un ejemplo tipo de esta situación, pues han sido ampliamente utilizados por los habitantes de estas regiones, por su madera, sitios de pastoreo o la recolección de piñones.

ANTECEDENTES

Los bosques de piñoneros son masas arboladas puras o mixtas y se ubican en los macizos montañosos enclavados o circundantes a las zonas áridas y semiáridas del país; generalmente se desarrollan bajo condiciones ambientales restrictivas, entre otras el agua.

Pinus cembroides Zucc. y Pinus discolor Bailey y Hawks., son dos de los varios taxa presentes en el desierto chihuahuense. La distribución de P. cembroides es muy amplia, se extiende desde los Estados de Puebla, Veracruz y Tlaxcala en el centro de la República Mexicana, hasta el oeste del Estado de Texas en los E.U.A., entre los 1450 y 2700 msnm. Por otra parte, la distribución de P. discolor es más restringida, sus poblaciones principales se encuentran en la frontera de estos dos países, principalmente en el SE de Arizona, SW de Nuevo México y N de Sonora y Chihuahua, entre los 1300 a 2700 msnm; asimismo al sur del paralelo 30°N, se encuentran poblaciones de esta especie en los Estados de Chihuahua, Durango y San Luis Potosí; este estado es donde se presente quizás su límite de distribución meridional, coexistiendo frecuentemente con la primera especie (Martínez 1948; Bailey y Hawksworth 1979; Passini 1982; Bailey Snajberk y Zavarin 1982; Bailey y Hawksworth 1983; Zavarin y Snajberk 1985 y Zavarin y Snajberk 1986).

Entre las principales características que diferencian a estas especies, se tiene a la ausencia de estomas en la cara dorsal de las acículas de P. discolor, mientras que en P. cembroides, las hojas son anfistomáticas (Bailey y Hawksworth 1979). Esta diferencia estomática permitiría suponer una respuesta diferente en el balance hídrico en las dos especies.

Como ha sido comentado por Waring y Cleary (1967); Ritchie y Hinckley (1975) y Kramer (1983) entre otros, la referencia más satisfactoria de la condición hídrica de las plantas es a través de la medición del potencial hídrico (Ψw). Una forma de conocer lo anterior es por medio de la bomba de presión tipo Scholander, la cual es utilizada para conocer el estatus hídrico de las especies, al determinar el potencial de presión del xilema aplicando gas en la cámara de presión. La importancia de lo anterior se manifiesta al permitir de esta

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forma, conocer el modo en que las plantas responden a un factor tan importante y limitado como es el agua en estos lugares.

Con base en lo anterior, el objetivo del presente estudio fue el de determinar el comportamiento diúrno y anual del potencial hídrico en ambas especies, bajo la hipótesis de que la probable distribución de las poblaciones de P. cembroides y P. discolor este influenciada por un diferente balance hídrico.

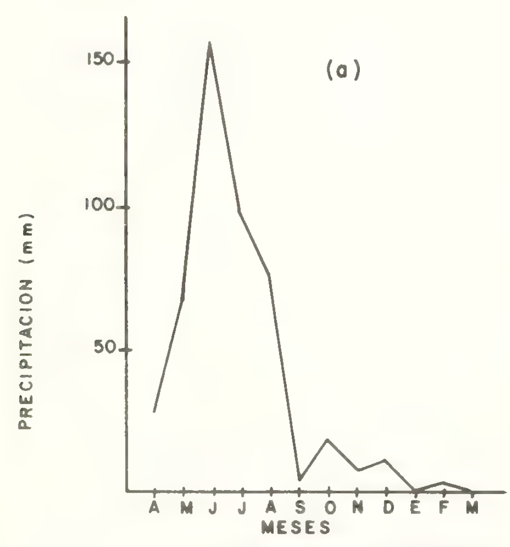
MATERIALES Y METODOS

El presente estudio se realizó en la localidad de La Amapola (21°56' N y 101°22'W), inserta en la región fisiográfica que Rzedowski (1965) denominó como Serranías Meridionales del Estado de San Luis Potosí. El lugar presenta un substrato ígneo de tipo riolítico y el suelo es de tipo litosol eútrico, con un pH que varía de 4.8 a 5.6; con un bajo contenido de mantillo, alto porcentaje de pedregosidad y claras evidencias de erosión. El clima de la región es templado, semiseco, extremoso y con un régimen de lluvias en verano (BS_1kw (e)g). La vegetación del lugar es de tipo encinar-piñonar, limitada hacia las partes bajas por pastizal y hacia las partes altas por chaparral de encinos (Quercus spp), Arctostaphylos pungens, y otras especies de pino. En la localidad se encuentran poblaciones puras y mixtas de P. cembroides y P. discolor en función de la exposición; las poblaciones puras de P. discolor se sitúan en exposiciones norte y noreste, las de P. cembroides en las sur, suroeste y oeste y las poblaciones mixtas en una amplia gama de exposiciones (Cetenal, 1973; Rebolledo, 1982; Avila, 1985). En este sitio se localizó un rodal mixto en un paraje con exposición noreste del Cerro del Capulín. Se utilizaron cinco árboles de cada especie, con diámetros normales entre 20 y 30 cm y 6 a 7 m de altura, no estando ninguno suprimido. Las mediciones del potencial de presión del xilema se realizaron con una bomba de presión tipo Scholander (modelo 600, PMS Cny.), utilizando aire comprimido e introduciendo en la cámara, de dos a cuatro ramitas de cada árbol, situadas entre 1 y 2 m de altura, y tomando en cuenta las recomendaciones dadas por Ritchie y Hinckley (1975). Las mediciones se efectuaron cada hora desde las 6:00 hrs hasta las 18:00 hrs, en un día a mediados de cada mes y durante un año (abril 85 a marzo 86). Para comparar los valores promedio de Ψw obtenidos de cada especie, se utilizó una prueba de "T".

RESULTADOS

La Figura 1 muestra los datos mensuales de precipitación registrados durante el período de estudio. Los meses con mayor precipitación fueron junio y julio, aunque en mayo y agosto se presentaron también valores altos. Por el contrario, desde septiembre se registraron bajas precipitaciones, en especial en los meses de septiembre, noviembre, diciembre y febrero o nula, como en enero y marzo. Asimismo, en la Figura 1 se observa la curva diúrna de Ψw registrada en el mes de abril. Se aprecian varias horas con diferencias significativas ($P<0.05$) y altamente significativas ($P<0.01$), en especial entre las 10:00 y 14:00 hrs. En las gráficas de los meses de mayo y junio (Figura 2), se observa una respuesta muy fluctuante o dinámica en los resultados obtenidos de Ψw, pues se encontró un constante aumento y disminución del mismo a lo largo del día; el Ψw no decayó más alla de -1.0 MPa en estos meses.

Conforme se presentaron las lluvias, el número



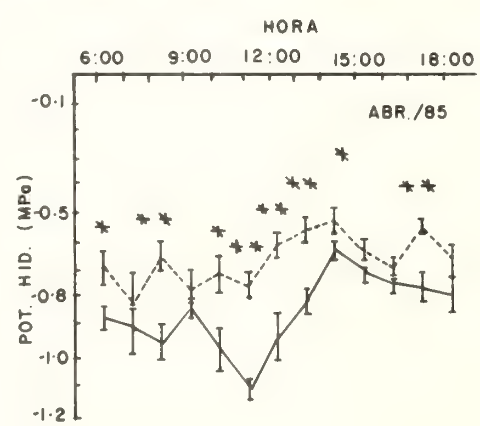


FIGURA 1.-(a) VALORES MENSUALES DE PRECIPITACION REGISTRADOS EN LA ESTACION DE EL PEAJE, S.L.P. Y CURVA DEL POTENCIAL HIDRICO DE P. discolor (---) Y P. cembroides (—) EN EL MES DE ABRIL DE 1985. LAS BARRAS INDICAN EL ERROR ESTANDARD. NIVELES DE SIGNIFICANCIA: * = P≤0.05, ** = P≤0.01.

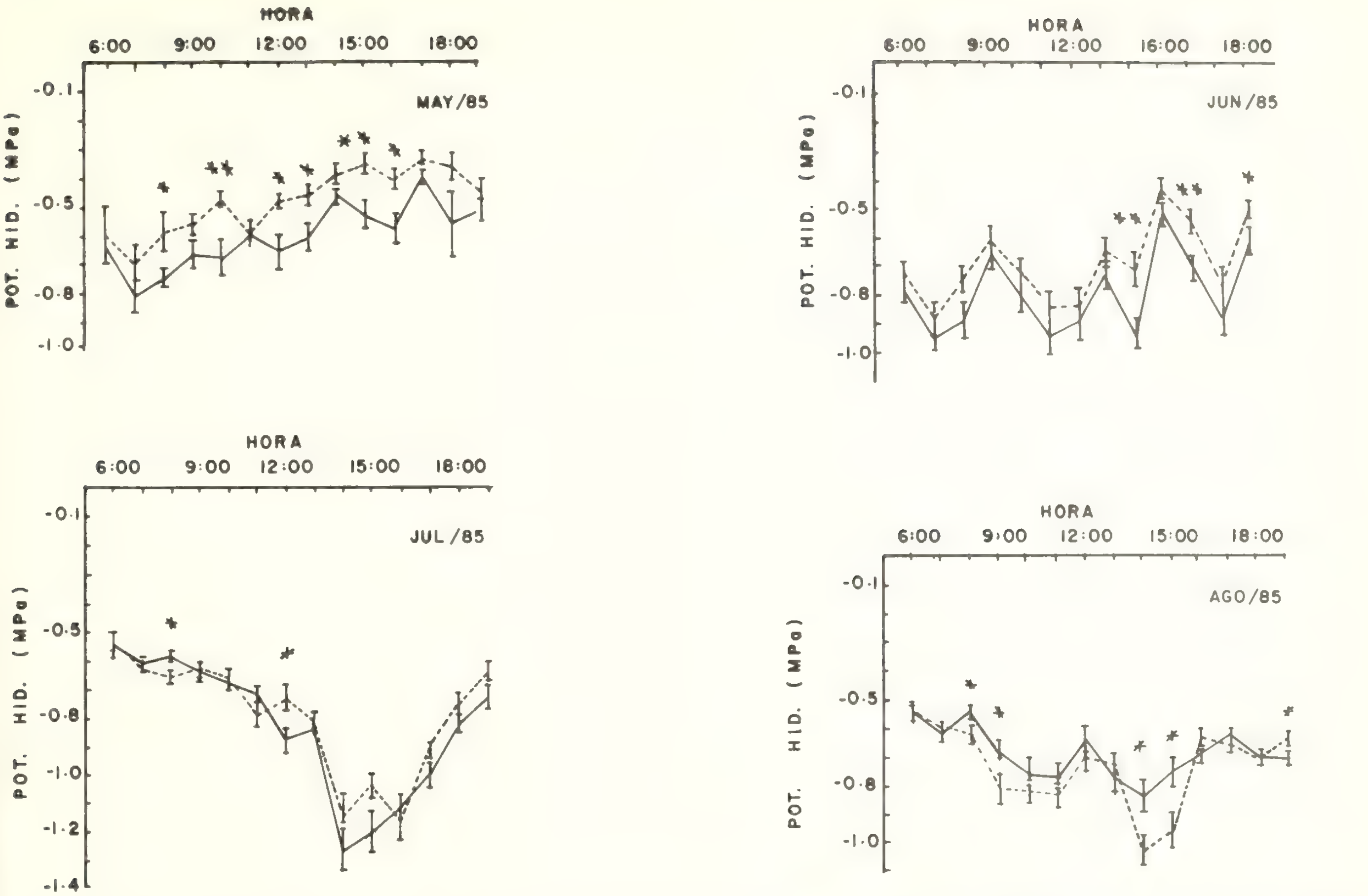


FIGURA 2.- CURVA DEL POTENCIAL HIDRICO DIURNO DE P. discolor (---)Y P.cembroides (—) EN LOS MESES DE MAYO, JUNIO, JULIO Y AGOSTO DE 1985. LAS BARRAS INDICAN EL ERROR ESTANDARD. NIVELES DE SIGNIFICANCIA: * = P≤ 0.05, ** = P≤ 0.01.

de horas con diferencias significativas entre las especies disminuyó; la medición del mes de julio solo registró dos horas con diferencias significativas (8:00 y 12:00 hrs.); asimismo se observó una seria disminución del Ψw a las 14:00 hrs en ambas especies, -1.14 MPa en P. discolor y -1.26 MPa en P. cembroides, ocacionado probablemente por un alto déficit de presión de vapor (DPV), que provocó un aumento en la demanda de humedad, la reducción del Ψw y un consecuente cierre estomático en las plantas, que se reflejó en el aumento progresivo del Ψw durante el resto de la tarde, pues a las 18:00 hrs, se registró un potencial de -0.64 MPa en P. discolor y -0.72 MPa en P. cembroides. Durante el mes de agosto (Fig. 2), se volvió a incrementar el número de horas con valores estadísticamente significativos y se presentó asimismo un comportamiento fluctuante en los valores de Ψw, i.e., un aumento y disminución de los valores, que pueden reflejar una apertura y cierre de los estomas. En este mes se registró una disminución marcada en el Ψw a las 14:00 hrs, llegando a -0.84 MPa en P. cembroides y -1.04 MPa en P. discolor. Esta ocasión fue una de las pocas veces en que se presentó un valor menor de Ψw en P. discolor en comparación con P. cembroides. Es interesante resaltar que durante la época de lluvias, no obstante la menor cantidad de horas con diferencias significativas, P. cembroides mostró valores más bajos de Ψw, aunque estos valores diferían, por lo general, en solo 0.1 MPa entre una y otra especie.

A partir del mes de septiembre se presentó una disminución en la precipitación (Fig.1), pues en este mes sólo se registraron 4.2 mm en total y se volvió a observar un aumento en las horas que presentaron diferencias estadísticamente significativas. En octubre (Fig. 3), se encontraron los potenciales hídricos más bajos (-0.9 MPa), registrados durante la primera medición del día (6:00 hrs) para las dos especies y disminuyeron en la siguiente hora a -1.05 MPa en ambas especies. Después de esta lectura, se presentó un comportamiento diferente en las dos especies, P. cembroides registró una mayor disminución del Ψw una hora después, ya que llegó a -1.2 MPa, mientras que en P. discolor se registró un aumento del Ψw (-0.9 MPa) en comparación con la medición anterior. Esta situación se volvió a dar en la medición de las 16:00 hrs, pues P. discolor y y P. cembroides presentaron valores similares (-0.96 MPa) a esa hora y en la medición posterior (17:00 hrs), P. discolor mostró un notable aumento del Ψw (-0.81 MPa) mientras que en P. cembroides disminuyó aún más (-1.13 MPa). Esta respuesta diferente podría indicar la presencia de valores umbral de Ψw distintos en las dos especies.

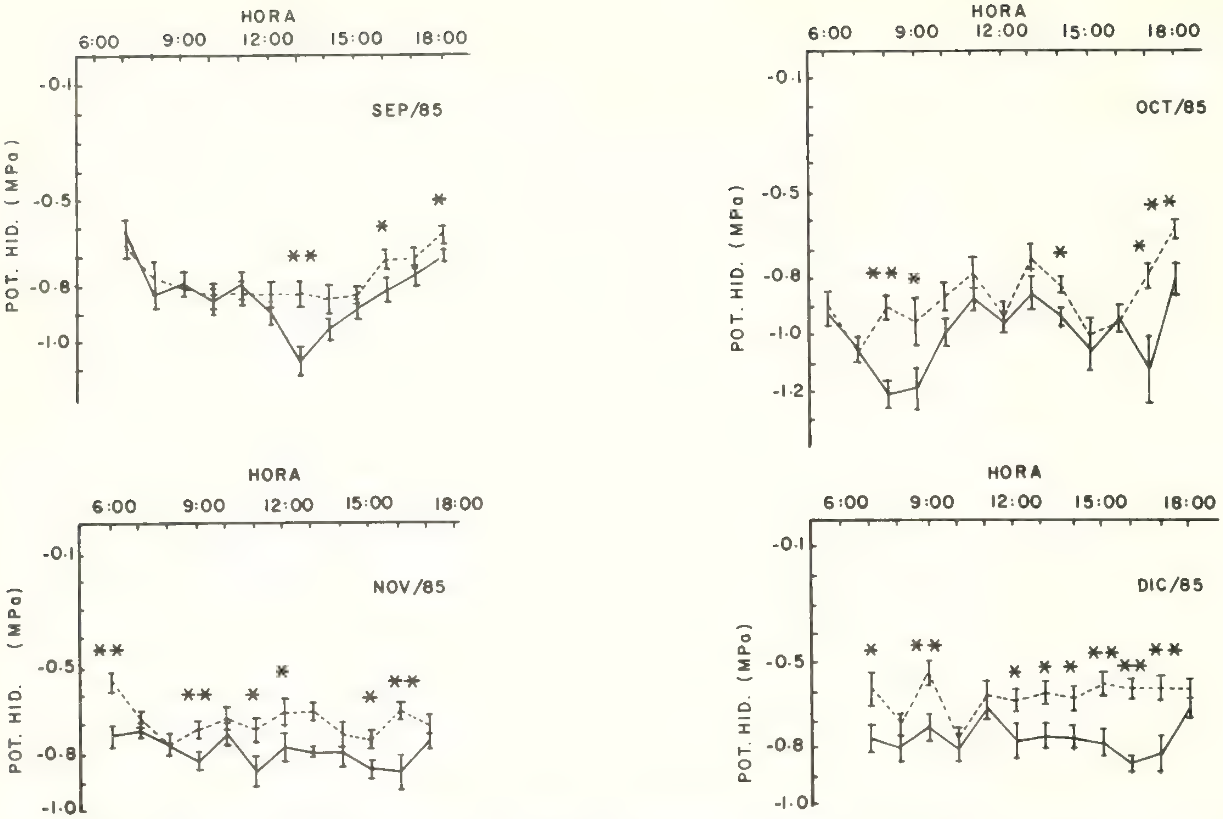
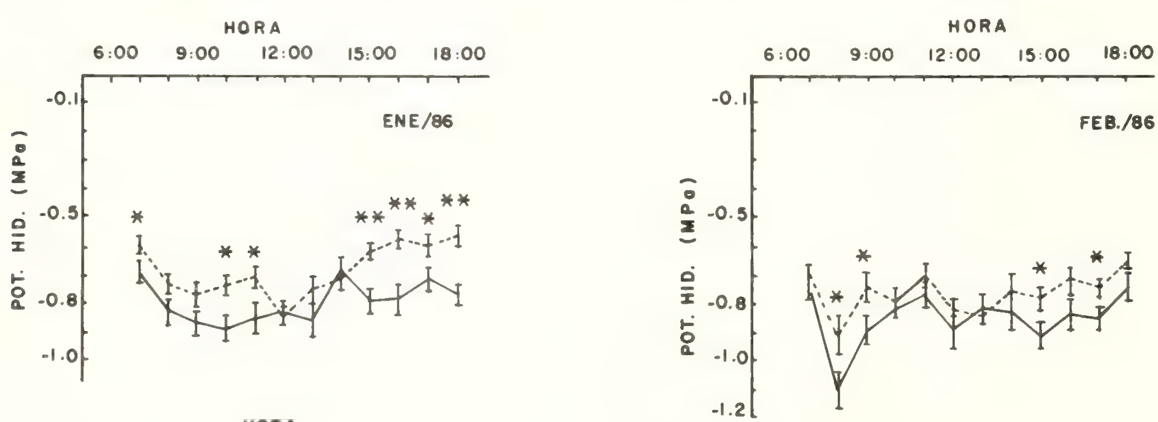


FIGURA 3.- CURVAS DEL POTENCIAL HIDRICO DIURNO DE P. discolor (---) Y P. cembroides (—) EN LOS MESES DE SEPTIEMBRE, OCTUBRE, NOVIEMBRE Y DICIEMBRE DE 1985. LAS BARRAS INDICAN EL ERROR ESTANDARD. NIVELES DE SIGNIFICANCIA: *=P≤0.05, **=P≤0.01.



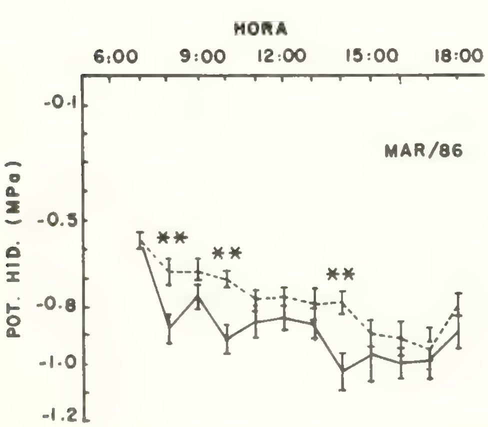


FIGURA 4.-CURVAS DEL POTENCIAL HIDRICO DIURNO DE P. discolor (---) Y P. cembroides (—) EN LOS MESES DE ENERO, FEBRERO Y MARZO DE 1986. LAS BARRAS INDICAN EL ERROR ESTANDARD.
NIVELES DE SIGNIFICANCIA: * = P≤ 0.05, ** = P≤0.01.

Este comportamiento fluctuante también es muy marcado durante los meses de noviembre y diciembre (Fig. 3). Durante estos meses no se registraron valores por abajo de -0.8 MPa en P. discolor y de -0.9 MPa en P. cembroides, no obstante la escasa precipitación mensual registrada.

En el mes de enero (Fig. 4), no disminuyó el Ψw de ambas especies de los valores mencionados anteriormente, aunque aumentaron los valores estadísticamente diferentes en ciertas horas de medición entre las dos especies, en especial hacia el final del día de muestreo. Pinus cembroides presentó comportamiento más fluctuante que P. discolor.

En el mes de febrero (Fig. 4), se observó una drástica disminución del Ψw a las 8:00 hrs en ambas especies; P. cembroides alcanzó valores de -1.1 MPa y P. discolor de -0.9 MPa, lo que ocasionó un cierre estomático muy marcado, sobre todo en P. cembroides, pues se registró un aumento constante del Ψw hasta las 11:00 hrs, presentándose posteriormente una fluctuación del mismo.

En el mes de marzo (Fig. 4), se observó un comportamiento del Ψw algo diferente a los meses anteriores, en especial en P. discolor, pues se registró una disminución progresiva del Ψw hasta las 17:00 hrs, llegando a -0.95 MPa a esa hora y aumentando después a -0.8 MPa a las 18:00 hrs. P. cembroides registró un comportamiento cambiante a lo largo del día y presentó una reducción mayor del Ψw a las 8:00 hrs, fluctuando posteriormente y llegando a -1.04 MPa a las 14:00 hrs.

DISCUSION

La información derivada del presente trabajo, muestra que P. discolor casi siempre presentó potenciales hídricos más altos (de 0.05 a 0.1 MPa o más) que P. cembroides. Aunado a lo anterior, en los meses de estiaje (septiembre a marzo), aumentaron las horas con valores estadísticamente significativos. Lo anterior podría indicar una diferencia en la pérdida de agua por las hojas o en la capacidad de absorción por las raíces entre las dos especies. Benavides (datos no publicados) no encontró diferencias en la conductancia estomática en una población mixta de estas especies en La Amapola, S.L.P., aunque el período de muestreo no fue tan amplio como el de este trabajo.

El comportamiento diurno del potencial hídrico encontrado en los pinos estudiados, no coincide con lo reportado por otros autores. Pereira y Kozlowski (1976) consignan para Abies balsamea y Pinus resinosa, un decremento constante de los valores de Ψw hasta ciertas horas del día, por lo general entre las 13 y 15 horas o antes, según las condiciones climáticas, y una recuperación posterior del Ψw durante las últimas horas de la tarde, incrementándose aún más por la noche. Una respuesta similar ha sido reportada también por Pereira y Kozlowski (1977) en Pinus banksiana y P. resinosa; Hellkvist y Parsby (1976) en Pinus sylvestris y Cline y Campbell (1976) en Pinus monticola y algunas latifoliadas.

Por otra parte, no se observó una reducción marcada del Ψw conforme se acentuó el estiaje, como lo menciona Kozlowski (1982) al citar varios trabajos, aunque sí hay cierta disminución del Ψw, lo cual se observa en los valores registrados durante la primera medición del día, pues por ejemplo, en el mes de julio (Fig. 2) el Ψw a las 6:00 hrs, estaba entre -0.53 y -0.55 MPa para las dos especies y en el mes de octubre se encuentra entre -0.9 y -0.93 MPa; sin embargo, hay cierta variación durante todo el año.

Por el tipo de respuesta de Ψw encontrado en estas dos especies en una población mixta, puede suponerse la presencia de un valor de umbral que ocasiona un cierre estomático total. Este valor estaría situado entre -1.1 a -1.3 MPa para P. cembroides, ya que nunca se encontró un valor por debajo de este último, aún en los meses bajo condiciones de escasa o mínima precipitación. En P. discolor este valor de umbral se encuentra situado en potenciales más altos, entre -0.9 y -1.1 MPa, ya que como en el caso anterior, no se encuentran valores por debajo de dicha amplitud. Aunado a lo anterior, es probable que los estomas de ambas especies sean sensibles a los cambios de DPV, como ha sido reportado por Goldstein, Brubaker y Hinckley (1985) en Picea glauca, lo cual permitiría explicar esa fluctuación diurna del Ψw, pues estaría en función principalmente de los aumentos de dicho factor. Lo anterior se pone de manifiesto en la reducción del Ψw que se presenta durante las primeras horas de la mañana, hasta cierta medición y el consecuente aumento del Ψw en las horas posteriores, sin haberse alcanzado los valores de umbral mencionados arriba. Este cierre estomático ocasiona un aumento del Ψw (como se observa en las figuras) y la rapidez con que se incremente dependerá del abasto de agua en el suelo o de la capacidad de absorción por las raíces, y que permitirá, posteriormente, una nueva apertura estomática, la cual se refleja en la disminución, una vez más, del Ψw en las horas subsecuentes. La relación entre la conductancia estomática y el potencial hídrico ha sido reportada por varios autores, entre los que destacan Hsiao (1973), Hinckley, Lassoie y Running (1978) y Kozlowski (1982) al citar a varios autores. Un ejemplo de lo anterior se presenta en las figuras de los meses de mayo y junio a las 7:00 hrs o en diciembre a las 8:00 hrs, aunado a las fluctuaciones diurnas registradas durante casi todos los meses. Por otra parte, un ejemplo del mecanismo de cierre estomático derivado de un valor de umbral puede apreciarse para P.cembroides en las figuras de abril (11:00 hrs), julio (14:00 hrs) septiembre (13:00 hrs), octubre (8:00 hrs) y febrero (8:00 hrs), en las cuales se observa un acentuado incremento del Ψw, en las horas posteriores a dicha medición, hasta llegar a cierto valor que ocasiona una nueva apertura estomática, si acaso el cierre estomático se presentó en las primeras horas del día, por ejemplo en los meses de octubre y febrero (Figuras 3 y 4, respectivamente). Para P. discolor lo anterior se aprecia en las figuras del mes de julio (14:00 hrs) y octubre (7:00 hrs).

Lo anterior explica el porqué de la ubicación de P. cembroides en las exposiciones más secas (sur y suroeste), debido a que el valor del umbral le permite tener sus estomas abiertos por un tiempo más prolongado en comparación con P. discolor, el cual los cierra más rápido y lo obliga a situarse en exposiciones menos extremas como lo son la norte y noroeste.

Este mecanismo derivado de un umbral ha sido reportado por Whitehead (1980) en P. sylvestris (-1.6 MPa); en Pseudotsuga menziesii (-20 barias) por Running (1976); Lopushinsky (1969) en Pinus contorta y Pinus resinosa (-14 a -17 barias) y en Abies grandis (-25 barias); en Quercus texana y Q. fusiformis (-4.2 y -3.2 MPa, respectivamente) por Fonteyn, McClean y Akridge (1985). En otras especies de piñoneros también se han reportado estos valores umbral. Barnes y Cunningham (1987) encontraron una reducción del Ψw de Pinus edulis en el período de sequía veraniega, situándose los valores mínimos de Ψw entre -1.85 a -2.26 MPa (más bajos que los encontrados en esta investigación) y reduciéndose la tasa neta de fotosíntesis en valores de Ψw de -1.8 MPa; estos autores comentan que la distribución de Pinus edulis esta limitada por su menor tolerancia al déficit hídrico en los habitats más xéricos y que los piñoneros sobreviven exitosamente largos períodos con escasa agua. Drivas y Everett (1987) reportan valores más bajos de Ψw en plántulas de Pinus monophylla que los citados en este trabajo, pues durante el mediodía, las plántulas llegaron a alcanzar hasta -2.4 MPa y mencionan la presencia de un umbral para las plántulas, situado entre -2.0 y -2.5 MPa, que cuando es alcanzado, se estabiliza por el resto del día.

Running (1976) comenta que este valor de umbral puede ocasionar que la conductancia estomática se reduzca hasta 10 veces, mientras que el mecanismo derivado del incremento del DPV, hace que se reduzca la conductancia solo en la mitad.

Fonteyn et al. (1985) comentan que las especies de Quercus con las cuales trabajaron, presentan un comportamiento del Ψw muy especial, lo cual los lleva a suponer que estas especies son evasoras a la sequía (drought avoidant), en función principalmente a que no presentan una marcada disminución del Ψw registrado al amanecer, con el medido en las horas subsecuentes, en comparación con Juniperus ashei, el cual sí muestra una disminución notable del Ψw a lo largo del día y en función principalmente con el DPV. El tipo de curvas en la respuesta diurna del Ψw de P. cembroides y P. discolor hacen suponer que en estas especies se da un mecanismo similar de resistencia a la sequía al evadir ésta, el cua les permite soportar largos períodos de falta de agua, muy frecuentes en estos lugares.

CONCLUSIONES

Por los resultados obtenidos en la presente investigación se concluye que P. cembroides y P. discolor presentan un mecanismo de cierre estomático que actúa al alcanzarse un valor de umbral de Ψw, el cual se sitúa en potenciales más altos para P. discolor, aunado a un cierre estomático en ambas especies debido principalmente al DPV. Por otra parte, P. cembroides mostró generalmente valores más bajos de potencial hídrico en comparación con P. discolor.

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A Baseline of Soil Erosion and Vegetation Monitoring in Desert Grasslands: Chihuahua, Texas, and New Mexico[1]

John A. Ludwig[2] and William H. Moir[3]

Abstract.--A long-term monitoring for vegetation and soil changes in desert grasslands of the northern Chihuahuan Desert was started in 1981 as part of the USDA/SEA Anti-desertification program. Five study areas were located on the Jornada Experimental Range, Otero Mesa, and Peloncillo Moutnains in New Mexico, Big Bend National Park in Texas, and Rancho La Campana in Chihuahua, Mexico. Vegetation was charted in quadrats along 30m permanent transects in these study areas. A high-precision auto-level was used to establish baseline data on the current soil-surface levels along the transects. In the future, recharting vegetation and remeasuring soil-surface level should provide data on rates of change. This data could be used to validate models designed to predict rates of soil erosion and vegetation change.

INTRODUCTION

Desert grasslands of the sunbelt Southwest U.S.A. and northern Mexico are extensive along foothills bordering mountains. Near areas of swelling populations, these desert grasslands are being utilized for housing and otherwise receive pressure from livestock grazing, recreation use and military operations. These is an urgent need to monitor these desert grasslands in order to have a record of their present extent and condition for future landuse planning.

The desert grasslands that exist today are largely remnants of much more extensive grassland areas (Humphery 1958). Large areas of desert grassland have already undergone desertification, defined and recognized by the replacement of perennial grasses by desert shrubs and ephemerals. Accompaning this change in vegetation is often serious soil erosion, thus monitoring trends in desertification is desert grasslands must include methods of measuring changes in both vegetation and soil-surface level. Through funding of the USDA/SEA's Antidesertification Program, we started vegetation and soil-surface level measurements on five desert grassland study areas in 1981. Future remeasurements will provide data to evaluate trends of desertification in these desert grasslands. The extent of natural and human-caused soil erosion should be evident from the data.

The purpose of this paper is to describe the baseline data that is available for remeasurement. We describe the details of the type of data available and the methods upon which the data is based. Although we focus our description on the La Campana study site in Chihuahua, Mexico, the same methods were used to collect the data for the other four study sites.

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STUDY AREAS

The desert grassland study sites being monitored are located (from north to south): (1) on the Jornada del Muerto Experimental Ranch in south-central New Mexico, (2) on Otero Mesa in south-east New Mexico, (3) in the Peloncillo Mountains in southwestern New Mexico, (4) in Big Bend National Park in Texas and (5) on the Rancho de La Campana in northern Chihuahua, Mexico (Fig. 1). These sites were heavily grazed by livestock late in the last century and early in this century, and in some cases more recently, but grazing is now either prohibited or strictly controlled.

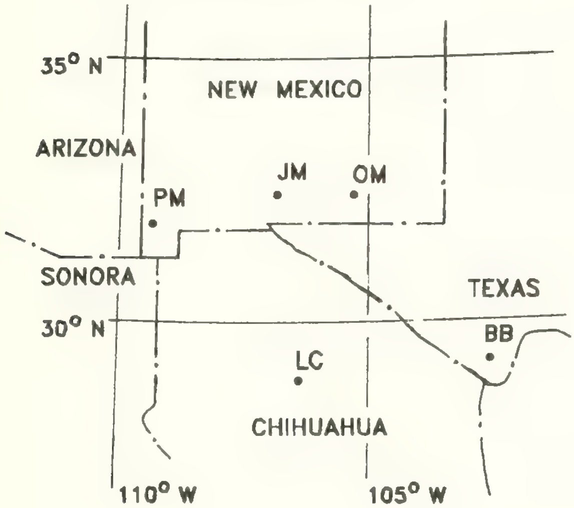

Figure 1. Location of the five desert grassland monitoring study areas (PM = Peloncillo Mountains, JM = Jornada del Muerto, OM = Otero Mesa, BB = Big Bend, and LC = La Campana).

The La Campana (LC) study area we are emphasizing is located on the slopes of a low hill (Loma La Sotolosa) on the Rancho Experimental La Campana in the State of Chihuahua, Mexico (Fig. 2). The study area is part of a series of pastures used for experiments dealing with different grazing trials. The Loma La Sotolosa pasture is grazed light to moderate on a seasonal basis (contact El Jefe, Rancho Experimental La Campana for grazing trial details on La Campana).

PERMANENT TRANSECTS

On each study area permanent transects either 25 m, 30 m or 40 m were established roughly to the contour on slopes of varying angle and aspect. Some transects have been placed across shallow, well defined arroyos, others along more even slopes with a highly defined microtopography.

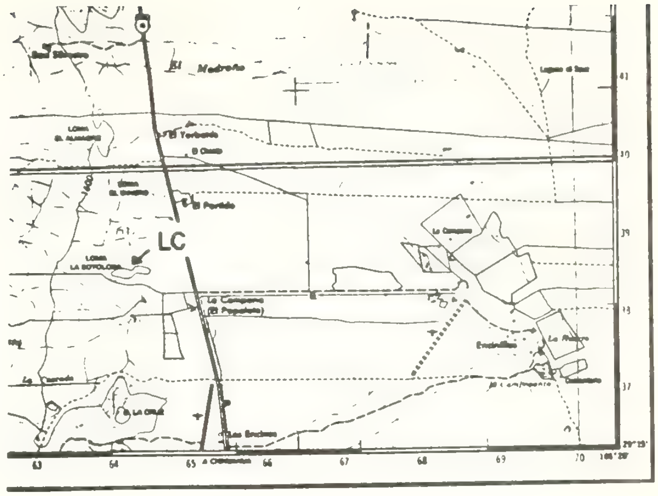

Figure 2. Location of the La Campana (LC) study area on the Rancho Experimental La Campana, Los Sauces Topographic Chart (H13C35), Chihuahua, Mexico.

Six permanent line transects were established for monitoring desertification trends in the desert grasslands on the slopes of Loma La Sotolosa (Fig. 3). The six transects vary from being on relatively gently slopes (LC-6 and LC-1) to relatively steep slopes (LC-2 to LC-5) face southeasterly (Table 1).

Figure 3. Position of the six La Campana (LC) permanent line transects on the slopes of Loma La Sotolosa.

Table 1.--Characteristics for the line transects on the Loma La Sotolosa, La Campana desert grassland monitoring study site.

TRANSECT NUMBER	ELEVATION METERS	FEET	SLOPE %	ASPECT DIRECTION	DEGREES
1	1575	5168	5	34° E of S	146°
2	1580	5184	23	2° E of S	178°
3	1590	5217	26	2° E of S	178°
4	1600	5250	29	12° E of S	168°
5	1610	5282	25	15° E of S	165°
6	1570	5152	2	25° S of E	115°

SURVEYING SOIL-SURFACE LEVEL

Near each transect a permanent benchmark was placed in bedrock. A high precision, auto-leveling surveyors transit (with a measuring accuracy of ± 2 mm over 1 km) was used to survey the surface profile at 0.5 m intervals (closer intervals were used on rough terrain) along each transect. Obtaining precise measurements between years requires that the permanent transect across the landscape must be precisely positioned each time. Steel rods about 1 m in length were driven into the soil to a depth of 75 cm (or to bedrock) in order to make the end of each line. The transect line was delimited with a high quality fiber-glass tape and was positioned as straight and as close to the soil surface as possible. The level must be positioned such that the observer is sighting exactly down or up the transect line (Fig. 4). This observer lines-up the person with the surveyers pole and records the elevation to the nearest mm. Each time a transect is measured, blind duplicate soil surface level observations were made, with a third observation made if the deviation between duplicate readings exceeded 3 mm. This procedure is particularily important if the landscape has high surface roughness as pole positioning becomes critical (e.g., on the side of a rock or stone). If the line position places the surveyors pole on the side of a steeply sloping rock, where no stable reading could be obtained, that position was discarded.

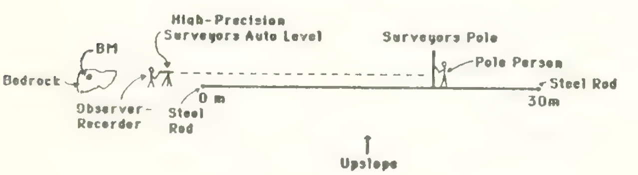

Figure 4. Diagram of the setup for surveying soil-surface levels along a permanent line transect relative to a benchmark (BM).

As an example of the type of data collected as part of the soil-surface level surveying procedure, a copy of a portion of the field form for Line 4 on the La Campana (LC) desert grassland monitoring (DGM) site is shown in Fig. 5. Elevation readings are made at 0.5 m intervals along transect line 4 relative to a benchmark (BM). Two "blind" readings are made, with a third reading taken if the difference between the first two readings is greater than 3 mm (e.g., reading at 3.5 m). The field form also shows that positions are discarded if the surveyors pole is on a sloping rock (e.g., readings at 0.5 m and 1.5 m). The elevation correction for the soil-surface along Line 4 relative to the benchmark (BM 2) is shown in Fig. 6, where the observer records the level of the benchmark and the line (west-end steel rod or rebar) from a fixed position (called a turning point, TP 0). The elevation of the soil surface along line 4 is obtained by subtracting the line readings from the benchmark reading (3.567). These "corrected" readings for the soil-surface level of Line 4 relative to benchmark 2 are listed in Fig. 7. From these readings, the soil-surface levels along the line can be plotted (Fig. 8). Note that Line 4 on the La Campana DGM site has a moderate amount of surface "roughness".

Pg 1 of 2

PROJECT	DATE YR	MO	DA	SITE	LINE NO.	TP	ELEVATION CORRECTION	LINE POSITION	SOIL SURFACE READINGS 1st	2nd	3rd
DGM	83	10	28	LC	4	0	3.567*	BM	3.567	3.567	
								West-End Rebar	0.902	0.902	
								~~0.5~~	Sloping Rock		
								1.0	1.390	1.393	
								~~1.5~~	Sloping Rock		
								2.0	1.269	1.268	
								2.5	1.162	1.162	
								3.0	1.210	1.209	
								3.5	1.173	~~1.183~~	1.172
								~~4.0~~	Sloping Rock		
								4.5	1.156	1.157	
								5.0	1.103	1.104	
								~~5.5~~	Sloping Rock		
								6.0	1.291	1.290	
								6.5	1.315	1.315	
								7.0	1.308	1.309	
								7.5	1.323	1.323	
								8.0	1.274	1.274	
								8.5	1.219	1.219	
								9.0	1.253	1.253	
								Edge of Rock 9.5	1.220	~~1.215~~	1.222
								10.0	1.327	1.326	
								10.5	1.180	1.180	
								on a rock 11.0	1.059	1.060	
								11.5	1.203	1.203	
								12.0	1.314	1.314	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	Pg 2 of 2
								25.0	1.070	1.070	
								25.5	~~1.025~~	1.033	1.030
								~~26.0~~	Sloping Rock		
								26.5	0.978	0.978	
								~~27.0~~	Sloping Rock		
								27.5	0.853	0.852	
								~~28.0~~	Sloping Rock		
								28.5	0.806	0.806	
								29.0	0.742	0.745	
								29.5	0.816	~~0.812~~	0.815
								30.0	0.855	0.855	
								East-End Rebar	0.575	0.575	

Figure 5. An example of a portion of the field form used to record soil-surface readings at 0.5 m intervals along a transect (La Campana Line 4).

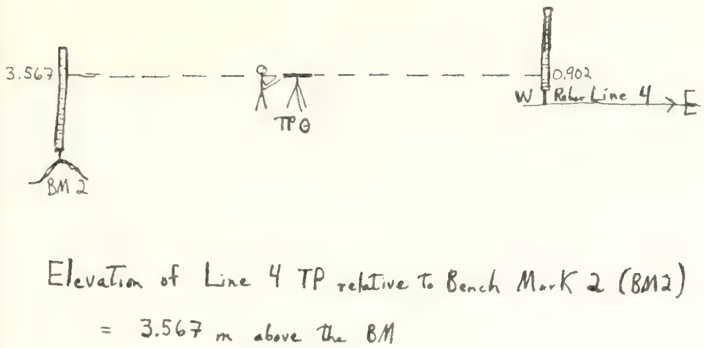

Figure 6. An illustration of the measurement of the "elevation correction" for the soil-surface levels (La Campana Line 4) relative to a benchmark (BM 2) from a surveyors turning point (TP 0).

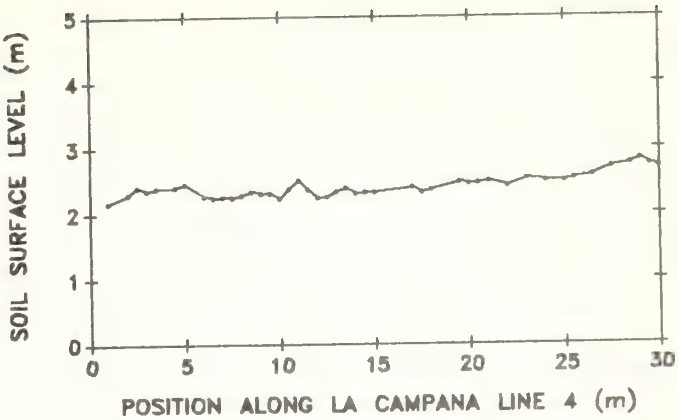

Figure 8. Plot of the soil-surface level readings along the 30 m of La Campana Line 4.

DGM	831028	LC	4	REBAR	2.665
DGM	831028	LC	4	1.0	2.176
DGM	831028	LC	4	2.0	2.299
DGM	831028	LC	4	2.5	2.405
DGM	831028	LC	4	3.0	2.358
DGM	831028	LC	4	3.5	2.395
DGM	831028	LC	4	4.5	2.411
DGM	831028	LC	4	5.0	2.464
DGM	831028	LC	4	6.0	2.277
DGM	831028	LC	4	6.5	2.252
DGM	831028	LC	4	7.0	2.259
DGM	831028	LC	4	7.5	2.244
DGM	831028	LC	4	8.0	2.293
DGM	831028	LC	4	8.5	2.348
DGM	831028	LC	4	9.0	2.314
DGM	831028	LC	4	9.5	2.346
DGM	831028	LC	4	10.0	2.241
DGM	831028	LC	4	10.5	2.387
DGM	831028	LC	4	11.0	2.508
DGM	831028	LC	4	11.5	2.364
DGM	831028	LC	4	12.0	2.253
⋮	⋮	⋮	⋮	⋮	⋮
DGM	831028	LC	4	20.0	2.460
DGM	831028	LC	4	20.5	2.475
DGM	831028	LC	4	21.0	2.500
DGM	831028	LC	4	22.0	2.420
DGM	831028	LC	4	23.0	2.542
DGM	831028	LC	4	24.0	2.506
DGM	831028	LC	4	25.0	2.497
DGM	831028	LC	4	25.5	2.536
DGM	831028	LC	4	26.5	2.589
DGM	831028	LC	4	27.5	2.715
DGM	831028	LC	4	28.5	2.761
DGM	831028	LC	4	29.0	2.824
DGM	831028	LC	4	29.5	2.752
DGM	831028	LC	4	30.0	2.712
DGM	831028	LC	4	REBAR	2.992

Figure 7. Soil-surface level readings for desert grassland monitoring (DGM) site on La Campana (LC) Line 4 made on 83/10/28 (year/month-/day).

CHARTING VEGETATION

Plant cover of each individual was estimated and mapped by species in 0.1 m^2 quadrats (0.2 m by 0.5 m) at 1 m intervals along each transect. Mapping or charting was facilitated by using a field form showing each quadrat gridded into 100 squares, that is, each square represents 1 % of the area of the quadrat. An example is shown for Line 4 on the La Campana DGM site (Fig. 9). Using a gridded quadrat greatly aided later laboratory determinations of percent cover by plant species. The percent cover of basal area, litter, soil and rock were also estimated for each quadrat and noted on the field form (Fig. 9).

The field data resulting from the charting of plant canopy cover in quadrats along the permanent line transects was then computer coded for subsequent analysis. An example for Line 4 on the La Campana site is shown in Fig. 10. This computer coded data was next used to compute summary tables giving the % canopy cover of each plant species in each quadrat along each line transect of each study site. Again, an example using Line 4 on the La Campana site is given (Fig. 11). These summary table computations were accomplished by using microcomputer programs written in FORTRAN.

[Note, that all field and coding forms used for later computer entry used the first 16 columns to uniquely identify each dataset (e.g., Figs. 5, 7 & 10). Thus, each data form and each line of data in the computer was uniquely identified as to project (DGM = desert grassland monitoring), collection date (year/month/day), study site (e.g., LC = La Campana) and line transect (e.g., Line 4). This coding greatly facilitated subsequent data analyses.]

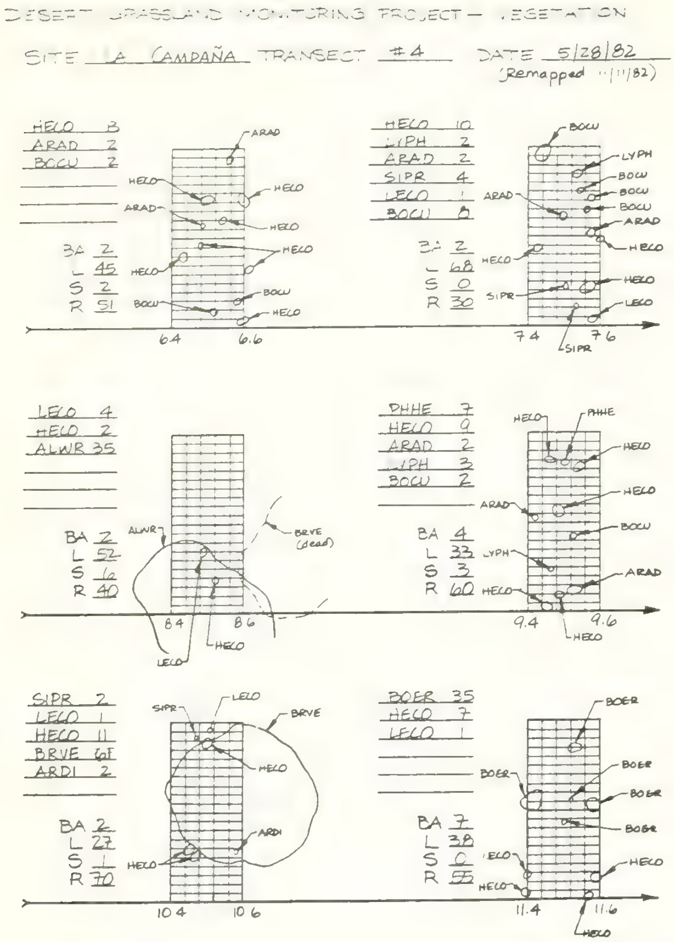

Figure 9. An example of the field form used for charting the canopy cover of plant species along La Campana Line 4. Individuals of each species (four-letter codes) are charted within the 0.2 x 0.5 m quadrat and percent cover for basal area (BA), litter (L), bare soil (S) and exposed rock (R) are estimated.

The plant species cover data was analyzed to examine vegetation structure by classifying the species in terms of: (1) type of photosynthesis, i.e., C_3, C_4, or CAM, (2) life history, i.e., annual, biennial or perennial and (3) growth form, i.e., grass, forb, sub-shrub, shrub, tree, leaf-succulent or stem-succulent. The 54 combinations of these three attributes were referred to as "life forms". We examined 18 lifeform patterns across each transect. In general, those transects with greater microtopographic variability had greater lifeform heterogeneity. For example, transects positioned across slopes with drainages and "rough" surfaces, had a greater variety of lifeforms than transects positioned across more gentle, uniform slopes. However, we found it difficult to interpret vegetation-microtopography relationships. Perhaps, remeasurements in the future may help resolve these dynamic patterns.

```
DGM 821111 LC  4  5   4 31  0 65 3DAWH 61BOBA  8HECO  5
DGM 821111 LC  4 15   3 37  0 60 2HECO  9BOBA  1
DGM 821111 LC  4 25   2 33  5 60 3BOBA  2HECO 12PHHE TR
DGM 821111 LC  4 35   4 65  1 30 5PHHE  1HECO 14BOBA  2BUJU  5BOCU  1
DGM 821111 LC  4 45   4 24  2 70 4HECO 17PHHE  2BUJU  1BOCU  6
DGM 821111 LC  4 55   3 36  1 60 4HECO  9BOBA  4BOCH  3BOCU  2
DGM 821111 LC  4 65   2 45  2 51 3HECO 13ARAD  2BOCU  2
DGM 821111 LC  4 75   2 68  0 30 6HECO 10LYPH  2ARAD  2SIPR  4LECO  1BOCU  8
DGM 821111 LC  4 85   2 52  6 40 3LECO  4HECO  2ALWR 35
DGM 821111 LC  4 95   4 33  3 60 5PHHE  7HECO  9ARAD  2LYPH  3BOCU  2
DGM 821111 LC  4105   2 27  1 70 5SIPR  2LECO  1HECO 11BRVE 61ARDI  2
DGM 821111 LC  4115   7 38  0 55 3BOER 35HECO  7LECO  1
DGM 821111 LC  4125   3 62  0 35 6HECO  8LECO  2ARAD  1LYPH  2DAWR  2DYDE  1
DGM 821111 LC  4135   3 47  5 45 3ARDI  1HECO  8SIPR  2
DGM 821111 LC  4145   1 49  5 45 5HECO  4ARDI  8ARAD  1PAHA TRENNU  4
DGM 821111 LC  4155   2 21  2 75 4ARDI  3HECO  6LECO  4BUJU  2
DGM 821111 LC  4165   3 20  0 77 4TEST 20BOCU  6SIPR  1LYPH  5
DGM 821111 LC  4175   4 26  0 70 4LYPH 13HECO  7BOCU  4SIPR  1
DGM 821111 LC  4185   6 19  0 75 3HECO  4LYPH  7BOCU  2
DGM 821111 LC  4195   3 25  2 70 6BOCU  3CRPO  3BUJU  1LYPH  8HECO  5BRVE 10
DGM 821111 LC  4205   3 27  0 70 3HECO  2DYDE  1LYPH  3
DGM 821111 LC  4215   2 33  0 65 4ENNU  1SIPR  4LYPH  6BOHI  5
DGM 821111 LC  4225   2 20  3 75 5HECO  2BUJU  2LYPH  6LECO  2BOHI  2
DGM 821111 LC  4235   4 25  1 70 6BRVE  1BUJU  1LYPH  9ASSP  1CRPO  3HECO  7
DGM 821111 LC  4245   2 40  3 55 6HECO  5LECO  3LYPH  2BRVE 80DYDE  3SIPR  2
DGM 821111 LC  4255   4 34  2 60 5HECO 15LECO  3PHHE  2SIPR  2DYDE  1
DGM 821111 LC  4265   7 26  2 65 3HECO  8LECO  3SIPR  1
DGM 821111 LC  4275   5 25  5 65 4HECO 12BOCU  4ARDI  3BRSP 25
DGM 821111 LC  4285   6 38  1 55 5HECO 10BOCU  1LECO  3LYPH  2SIPR  2
DGM 821111 LC  4295   3 25  2 70 5HECO  8BOCU  3BOHI  2LECO  1ENNU  3
```

Figure 10. An example of the computer coded plant species canopy cover data for the 30 quadrats located at 1 m intervals (beginning at .5 m and ending at 29.5 m) along Line 4 of the La Campana site.

DISCUSSION AND CONCLUSIONS

Permanent transects are now in place at five sites in the northern Chihuahuan desert (Fig. 1). Each transect represents a baseline measurement of soil-surface level and perennial plant cover taken in 1982, 1983, or 1984. With remeasurement of these permanent line transects after ten or twenty years (or longer), the trends and rates of change in vegetation (succession) or soil-surface level (erosion or deposition) should be evident (Ludwig 1985). As some transects are located on sites being protected from livestock grazing, while others are on sites with controlled grazing, the contribution of grazing to the rates of natural soil erosion might be evident.

In order to resolve differences in soil-surface level after, say after 10 or 20 years, remeasurement of the soil-surface level will have to be done very accurately, that is, a technique is needed which ensures remeasurement of exactly the same points along each transect. We recommend that future measurements be made by "line-of-sight" alignment of the "pole-person". The surveyors auto-level should be aimed directly down the line to position the surveying pole on the line before taking a elevation reading. This might be most accurately accomplished with a laser beam as presently used in other types of surveying, but our results suggest that careful and patient "team-work" between the surveyor and the pole-person can produce highly accurate and repeatable results. Of course, the steel-rods marking the ends of the transects must be truly permanent. And, the closer the benchmark is to the transect, the better the measurement precision is to the benchmark (needed as a reference for the soil-surface levels).

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
														QUADRAT																
ALAYSIA WRIGHTII									35																					
ARISTIDA ADSCENIONIS							2	2		2			1		1															
ARISTIDA DIVARICATA											2			1	8	3												3		
ASTRAGALUS SPECIES																								1						
BOTHRIOCHLOA BARBINODES	8	1	2	2		4																								
BOUTELOUA CHONDROSOIDES						3																								
BOUTELOUA CURTIPENDULA				1	6	2	2	8		2							6	4	2	3								4	1	3
BOUTELOUA ERIOPODA												35																		
BOUTELOUA HIRSUTA																						5	2							2
BRICKELLIA SPINULOSA																												25		
BRICKELLIA VERONICAEFOLIA											61									10				1	80					
BULBOSTYLIS JUNCOIDES				5	1											2				1			2	1						
CROTON POTTSII																				3				3						
DALEA WRIGHTII													2																	
DASYLIRION WHEELERI	61																													
DYSCHORISTE DECUMBENS													1								1				3	1				
ENVOLVULUS NUTALLIANUS															4							1								3
HELIOTROPIUM CONVOLVULACEUM	6	9	12	14	17	9	13	10	2	9	11	7	8	8	4	6		7	4	5	2		2	7	5	15	8	12	10	8
LEPTOLOMA COGNATUM								1	4		1	1	2			4							2		3	3	3		3	1
LYCURUS PHLEOIDES								2		3			2				5	13	7	8	3	6	6	9	2				2	
PANICUM HALLII															TR															
PHASEOLUS HETEROPHYLLA			TR	1	2					7																2				
SIDA PROCUMBENS								4			2			2			1	1				4			2	2	1		2	
TECOMA STANS																	20													

Figure 11. An example of the summary table for plant species canopy cover in the 30 quadrats along Line 4 of the La Campana site.

Along each transect, the canopy cover of each species was also charted. Future recharting of the vegetation will provide data on trends of desertification, that is, changes in plant composition from perennial grasses to shrubs and ephemerals. Such changes have already occurred in much of the northern Chihuahaun Desert (Branscomb 1958, Buffington and Herbel 1965, Gardner 1951, Glendening 1952, Herbel et al. 1972, York and Dick-Peddie 1969).

A description of the desert grassland monitoring project, it's methods and the baseline data for each site is available from the following individuals representing the given site:

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Design and Operation of a Water-Harvesting Agrisystem[1]

Martin M. Karpiscak, Kennith F. Foster, and R. Leslie Rawles[2]

A water harvesting agrisystem for growing crops on retired irrigated farmland was developed. The soil surface was shaped and after shaping, sodium chloride was raked into surface and the catchments were compacted. Plants such as eucalyptus, Mondell and Aleppo pines, Arizona cypress, peaches, apples, apricots and saltbush have been successfully grown.

INTRODUCTION

The rising cost of pumping, increased competition for water, and legal restrictions on its use have caused farmland to be retired from irrigated agricultural production in Arizona. In Pima County the City of Tucson has purchased nearly 9,000 hectares and almost all the remaining 10,000 hectares are projected to be idled by the year 2020 in large part due to the 1980 Groundwater Law. This law encourages the retirement of irrigated farmland so that the groundwater may be transferred to municipal or industrial use (Karpiscak et al., 1981; Wright, Taylor and Foster, 1985). Although other cities, such as Phoenix, and mines in the western United States are purchasing and retiring farmland, the City of Tucson is one of the largest owners of retired farmland in the county.

Retired farmland in arid and semi-arid areas presents both a problem from the standpoint of revegetation as well as an opportunity as an untapped economic resource. Russian thistle (Salsola kali) quickly becomes established on fallowed fields, particularly in the spring. These plants mature in the fall and upon senescence are blown into neighboring farms and roadways causing considerable management problems (Karpiscak, 1979).

The heavy clay soil of some semiarid ecosystems such as those in Avra Valley have a tendency to form surface crust which prevent moisture penetration. Therefore, once these areas have been disturbed and abandoned they do not revert to stable desert plant communities without considerable passage of time, if at all, and weeds, dust and erosion become problems.

Dryland farming has been practiced in many of the world's arid areas for thousands of years. In the Negev Desert of Israel, over 2,000 years ago, the Israelites captured rainwater and directed it to their cultivated areas (Evenari et al., 1971). In Arizona, Native Americans developed highly site-specific floodwater farming techniques (Nabhan et al., 1980). Today in states such as Texas and California dryland farming is practiced and is predicted to increase as water tables decline (Luebs, 1970; Mulkey et al., 1985).

CONSTRUCTION

The Water Harvesting Agrisystem is located within the Upper Santa Cruz Sub-basin in Avra Valley, Arizona now owned by the City of Tucson. This area is only 30 km from this rapidly growing city.

The average annual rainfall reported for Avra Valley does not exceed 250 mm. The rainfall is about evenly divided between two rainy seasons (winter and summer).

SITE SELECTION

Site selection is a critical factor in the success of a water harvesting agrisystem (Shanan and Tadmor, 1979; Matlock and Dutt, 1984). Soils in arid and semiarid regions should be deep to provide soil storage of water directly in the crop area. Soils also should have a clay content greater than 20 percent. In the areas selected for catchment construction, the fine-textured soil should be close to the surface

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(grading or plowing could then be used to expose the clay). In the planting areas clay soil is needed to provide adequate soil-moisture storage for the plants being grown.

The site should be fairly level and slopes should not exceed 8 percent to minimize problems associated with erosion from intense rainfall (Shanan and Tadmor, 1979; Frazier, 1981).

CATCHMENT CONFIGURATION

The land surface was shaped by use of a road grader or a combination of disking and plowing. The 16 catchments are V-shaped and cover about 1.6 ha. A standard length of 100 m and a slope of 0.5 percent was used. Catchment widths vary from 6 m to 8 m. The sides of the catchments were treated with 5,000 kg/ha NaCl and compacted with a roller-compactor (Dutt et al., 1983). Untreated planting areas (1.25 m) were situated at the bottom of the V-shaped catchments. Thus rainfall from the treated and compacted areas drains toward the plants. Excess runoff flows down the planting areas into a collecting channel and into a shallow sump.

RESERVOIRS AND IRRIGATION SYSTEM

The combined design capacity for the 2 gravity-fed sumps and the main storage reservoir is approximately 2,400 m^3 of water. The main reservoir and sump were treated with NaCl to decrease seepage. The main reservoir is also covered with 250,000 plastic film cans to decrease evaporation.

The irrigation system consists of a 6,000 W centrifugal pump, an 8 cm PVC pipeline connecting the sump and reservoir to the pump, a 5 cm PVC pipeline connecting the pump to the field plots, and 2 cm polyethylene driplines equipped with 0.01 m^3 or 0.02 m^3 per hour drip emitters (Reed Model E-2 and E-4). The system permits movement of water from sump to reservoir and from either the sump or reservoir to the field. Screens on the input ends of the 8 cm pipeline help prevent foreign material such as weeds from entering the system, and a fine mesh filter is installed in front of the water meter. Polyethylene driplines are attached to gate valves at the head of each catchment and removable screw caps at the ends of the PVC lines facilitate cleaning of the system.

OPERATION

Operation and monitoring of the water harvesting agrisystem is continuing. Reservoir water levels, evaporation rates, water quality, rate of plant growth, percent survival and other parameters are being studied.

The irrigation system and stored water are utilized primarily to maintain recently transplanted seedlings. If sufficient water is available in the reservoirs, supplemental irrigation of established plants is utilized to stimulate growth.

Rainfall

The annual rainfall for the agrisystem has varied from 207 mm to 578 mm for the period October 1982 through September 1987 (Table 1). The low rainfall of 1987 demonstrated the importance of water storage to insure the survival of plants during times of drought. During the 6-month period from March 1987 through August 1987 a total of only 47 mm of rainfall was recorded.

Table 1.--Rainfall recorded at the Avra Valley water harvesting agrisystem

Water Year[1]	mm	Inch
1983	317	12.49
1984	578	22.76
1985	280	11.02
1986	237	9.34
1987	207	8.16

[1]Water Year = October 1 - September 30.

Reservoir Water Storage

Water levels of the reservoir are measured weekly and storage volumes determined. The arid foresummer typically is the period when storage volumes are lowest and the peak volumes occur during the winter rainy season.

Table 2.--Total reservoir storage volumes

	Jan (m^3)	April (m^3)	July (m^3)	Oct (m^3)
1982	--	--	--	745
1983	869	1002	394	1048
1984	810	683	431	911
1985	898	818	438	500
1986	714	931	562	825
1987	752	889	538	423

Evaporation Control

A major problem of reservoirs in arid areas is evaporation during long-term storage (Cluff, 1981). Evaporation losses in storage reservoirs are difficult to control. Generally, there are four approaches for evaporation suppression: 1) reducing the water surface area; 2) decreasing the wind velocity directly over the reservoir; 3) decreasing the input of solar energy that penetrates the water surface; or 4) covering the reservoir with some impermeable barrier.

Black plastic film cans were obtained from Eastman Kodak Corporation. These cans measure 30 mm in diameter by 50 mm in length; therefore, approximately 480 plastic cans were needed to cover one square meter. The cost per square meter was about $5.20.

These black plastic film cans have resisted the destructive effects of ultraviolet radiation and they do not appear to leak. They appear to be effective in reducing wave action and are self-adjusting to changes in water levels. Visual evaluation has revealed little if any degration after 4.5 years. These results correspond with an earlier report on black balls, 45 mm in diameter, made with polyethylene and a 2 to 5 percent admixture of carbon black. The balls were used to reduce odors emanating from noxious liquids (Anonymous, 1972).

The black plastic film cans reduced evaporation by an average of 51 percent (Table 3).

Table 3 .--Annual evaporation from open and covered pans

Water Year[1]	Open (mm)	Covered (mm)	Percent Decrease
1984[2]	3331	1512	54.6
1985	3966	2183	45.0
1986	3820	1768	53.7
1987	3890	1859	52.2

[1]Water Year=October 1 - September 30
[2]Covers a period of about 11 months

Plant Growth

Species planted at the agrisystem have included both annual and perennial species. Initial evaluation of annual species such as corn and watermelon indicated that these species could be successfully grown. However, the lack of fencing to protect plants from livestock as well as wildlife and the additional labor required to maintain annuals made it difficult to continue planting these species.

Planting of perennial trees and shrubs have proven successful with some exceptions. Jojoba (Simmondsia chinensis) failed to survive the heavy soils and below freezing temperatures found at the agrisystem. Grapes were established but browsing by wildlife proved too heavy and impossible to overcome.

Peach, apple and apricot seedlings have been successfully established. The major problem in maintaining these fruit trees has been browsing by deer and cattle. Deer have been repelled by use of the fertilizer blood meal. Cattle continue to be an intermittent but highly destructive problem.

Eucalyptus microtheca seedlings were transplanted to the field in 1982 and irrigated by dripline for the first year. After the first year the only water provided the plants was that which was concentrated by the catchment. The average tree height after 5 years was 3.8 m (Table 4).

Table 4.--Average tree height for Mondell Pine, Arizona Cypress and Eucalyptus

	Mondell Pine (30 plants)	Arizona Cypress (41 plants)	Eucalyptus (28 plants)
Sep 82	293	377	
Nov 82			622
Apr 83	347	534	
Nov 84	1351	1692	2135
Nov 85	1879	1986	3141
Nov 86	2206	2118	
Dec 86			3843
Oct 87	2541	2277	

Mondell Pine (Pinus eldarica) seedlings have reached an average height of 2.5 m after 5 years of growth. Supplemental irrigation following the first year of irrigation has only been required on a monthly basis during the summer. Only 1 tree has died from disease; however, numerous individuals have been lost from flooding during October 1983 and unauthorized removal.

Arizona Cypress (Cupressus arizonica) plants appear to be more tolerant of stress and have been easier to establish as seedlings than the Mondell Pines. They form dense canopies and provide a good wind break. Table 4 shows the growth of Arizona Cypress as recorded at the agrisystem.

Other perennial species such as guayule (Parthenium argentatum) and saltbush (Atriplex canescens) have also required little if any additional irrigation.

Evaluation of the agrisystem indicates that the salt-treated compacted earth water harvesting system is a technical success. Water harvesting techniques and selection of appropriate arid adapted species may provide a means to stimulate the revegetation of retired groundwater irrigated farmlands.

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MANEJO INTEGRADO DE LA CUENCA HIDROLOGICA "EL PLATEADO"[1]

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Resumen.--Este trabajo se estableció para resolver los problemas de desertificación, utilizando una cuenca hidrológica para estudiar los bancos, flujos y tasas de intercambio de la energía, agua y nutrimentos. Se contempla la investigación integral del hombre en sus interrelaciones con el medio que permitirá una aplicación universal de la tecnología generada.

INTRODUCCION

La preocupación por los procesos erosivos, y en especial el de desertificación, si bien han sido reconocidos académicamente desde la creación de las ciencias del suelo, no alcanzó una concientización mundial, sino hasta el dramatismo de los sucesos de el Sahel en 1973.

Con base en estos sucesos, el Programa de las Naciones Unidas para el Medio Ambiente (PNUMA) organizó una reunión en Nairobi, Kenia en 1977; de esta reunión se desprendió la preocupación de México por comenzar a estructurar investigación específica para prevenir y conocer los procesos que se involucran en la desertificación. Esta se entiende como el proceso de disminución progresiva en la productividad biológica, causada por la interacción de los cambios biogeoclimáticos que controlan el ecosistema y el manejo inadecuado que el hombre hace de dichos ecosistemas.

El Comité para Prevenir y Combatir la Desertificación en México, quedó estructurado en 1979, y lo conformaron varias dependencias de la Secretaría de Agricultura y Recursos Hidráulicos. En el planteamiento que hizo el Comité, se consideró indispensable el establecimiento de áreas piloto para investigación que fueran representativas de los ecosistemas sujetos a la desertificación. Es así como se identificó la Cuenca Hidrológica de "El Plateado" en la zona de Los Cañones en el estado de Zacatecas, como una de estas áreas.

La Cuenca Hidrológica, como unidad integradora de los recursos naturales, es útil en términos del enfoque de sistemas, para evaluar los efectos debidos a la intervención de la mano del hombre en el uso de los recursos naturales renovables. Procesos de importancia trascendental como es la desertificación, podrán ser evaluados al conocer indicadores de tipo biológico y social, que indiquen la tasa de cambio en el proceso de desertificación.

El uso que se le de a los recursos naturales de una cuenca hidrológica se verá reflejado en los componentes del ciclo hidrológico, ya que el agua es el factor que limita en ecosistemas áridos y semiáridos (Noy-Meir 1974). El involucrar al hombre en el entendimiento del balance hidrológico de una cuenca hidrológica, pone de manifiesto la escasez de metodologías que permitan cuantificar las verdaderas causas de lo que está sucediendo en un sistema complejo, donde se incluye la toma de decisiones del productor usuario de los recursos de la cuenca hidrológica.

El proyecto plantea como característica indispensable e inseparable de la estructura y funcionamiento de los ecosistemas las actividades del hombre, de esta forma visualizamos como objetivos: 1) desarrollar una metodología de investigación en manejo integrado de cuencas hidrológicas extrapolable a otras cuencas del país y 2) prevenir y combatir la desertificación, y lograr una producción máxima aprovechable y sostenida, lo anterior sin detrimento del medio físico y biológico, de los sistemas forestales, agrícolas y pecuarios, mediante una concepción integral de investigación, desarrollo técnico y socioeconómico de los habitantes.

Estos objetivos contemplan tres acciones específicas: 1) realizar una investigación de tipo integral, 2) utilizar los componentes del ciclo hidrológico como indicadores de los cambios en el uso de los recursos renovables y 3) evaluar la participación del hombre en la modificación de los bancos, flujos y tasas de intercambio de la energía, agua y nutrimentos.

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[1]Ponencia presentada en la Reunión Estrategias de Clasificación y Manejo de Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas. [Tucson, Arizona, 12-16 de Octubre de 1987].

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De esta forma, se consideran como metas del proyecto: 1) obtener información básica de los elementos agua, suelo, planta, animal y socioeconómico, para el entorno específico de la cuenca y 2) implementar líneas aplicadas dentro de dichos elementos para resolver los objetivos a través de la estructuración, desarrollo y evaluación de sistemas de producción agrícola, ganadera y forestal, usando el conocimiento tradicional, así como introducción de tecnología y germoplasma

MATERIALES Y METODOS

El medio físico-biológico

El área seleccionada se localiza en el Norte-Centro de México, en el estado de Zacatecas, tiene una superficie de 17,960 ha, ubicada entre los paralelos 21° 48' y 21° 57' N y los meridianos 102° 55' y 103° 09' W, comprende parte de cuatro municipios que es la unidad de división política en México. El parteaguas se encuentra en la Sierra de Morones a 1,640 msnm y el terreno desciende hasta llegar a 1,480 msnm en el lecho del Río Juchipila. La zona forma parte de la cuenca Lerma-Santiago que desagua al Oceano Pacífico.

En la parte baja de la cuenca domina el clima semiseco, semicálido $BS_1hW(W)$ (Koppen modificado por García 1973), caracterizado por lluvias en verano con un porcentaje de precipitación invernal menor de 5. La precipitación media anual fluctúa entre 350 y 800 mm, y la temperatura media anual oscila entre 18 y 22°C. La máxima incidencia de lluvias se presenta en julio con un rango de 110 a 120 mm. La temperatura máxima se registra en junio con un valor entre 25 y 26°C y la mínima se presenta en enero, que es de 16 a 17°C. En la parte baja de la cuenca, las pendientes son menores de 6%, los suelos profundos de origen aluvial y coluvial, clasificados como clase II.

En la parte media de la cuenca, la topografía es ondulada, su material geológico es ígneo y sedimentario. Los suelos son delgados a profundos, de textura media y formación *in situ*.

El matorral subtropical se localiza en las partes media y baja de la cuenca. Las especies dominantes de este tipo de vegetación son de los géneros: *Bursera*, *Ipomoea*, *Myrtillocactus*, *Cathestecum*, *Bothriochloa*, *Eysenhardtia*, *Acacia*, *Prosopis* y *Mimosa*, estas últimas tres como indicadoras del disturbio presente en esta área.

La parte alta de la cuenca hidrológica comprende las estribaciones de la sierra, el clima es templado subhúmedo, C (W_o) (W), con lluvias en verano y porcentaje de lluvia invernal menor de 5%. La precipitación media anual varía entre 600 y 800 mm, la máxima ocurrencia de lluvia se registra en junio con un valor de 170 a 180 mm. La temperatura máxima fluctúa entre 19 y 20°C en junio y la mínima se registra en enero, con un valor entre 11 y 12°C, la frecuencia de heladas fluctúa de 10 a 40 días al año. La pendiente varía de 3 a 12%. El material geológico es ígneo y los suelos son de textura media a fina.

En general, en la cuenca hidrológica un 62% del área son suelos del tipo regosol y un 26% son castañozem (FAO modificado por CETENAL 1970).

El bosque esclerófilo caducifolio se localiza en la parte alta de la cuenca, los géneros dominantes son: *Quercus*, *Arbutus*, *Arctostaphylos* y *Pinus*. El pastizal mediano con encino se encuentra ubicado en los límites con el bosque esclerofilo en la parte media de la cuenca. Dominan especies de los géneros *Quercus*, *Bouteloua*, *Muhlenbergia*, *Stipa*, *Aristida* y *Cathestecum*.

La región donde se ubica el proyecto, tiene un alto índice de crecimiento. El apoyo económico en la zona está dado, en parte por BANRURAL, pero un apoyo considerable se da en función de los dólares que ingresan por concepto de remuneraciones por trabajo de algunos miembros de las familias en el extranjero. Es importante señalar que existe un movimiento migratorio a Estados Unidos del 80% y hacia el interior del país de un 8% de la población activa. El 94% de los habitantes son pequeños propietarios y el resto son ejidatarios. La población aproximada de la cuenca es de 2,500 habitantes, de los cuales 495 son productores organizados en 300 familias. La densidad de población es de 13.9 habitantes/km^2. La población económicamente activa es de aproximadamente el 20%.

Metodología

La solución al problema de la desertificación implica por lo tanto, el análisis de las relaciones causa-efecto de todos los fenómenos observados a lo largo de la cadena, hasta definir las causas más susceptibles de ser modificadas y enfocar ahí los esfuerzos. Para esto se requiere de la visión global que resulta de la participación de diversos especialistas en un grupo multidisciplinario con un enfoque de investigación integral.

Por esta razón, se estructuraron cuatro proyectos de investigación que cubren todos los aspectos que afectan o se ven afectados por la desertificación. Cada proyecto se compone de varios subproyectos que fueron definidos en la etapa preliminar del programa, una vez elaborado el Marco de Referencia e identificados los problemas principales del área. Cabe aclarar que este planteamiento inicial fue la primera aproximación y ha evolucionado a lo largo del desarrollo del programa, obviamente está sujeto a nuevas modificaciones en caso de que así se requiera, no se concibe un programa estático de este tipo.

La estructura de investigación del programa contempla un enfoque macro y un micro, en un primer plano, utilizando la subdivisión natural hidrológica de la cuenca; se establecieron tres cuencas parcialmente instrumentadas representando los usos del suelo más comunes en esas macrocuencas. De tal manera, se tiene una cuenca forestal (cuadro 1) con

Cuadro 1.--Características Físicas de las Cuencas Experimentales INIFAP-Zacatecas-México.

Cuenca	Vertedor	Superficie (ha)	Longitud Cauce Principal (m)	Orden (Horton)	Pendiente media (Nash) (%)	Forma	Profundidad del suelo (cm)	Estrato geológico
Forestal	Tringular cresta gruesa Q= 2.83 m^3/s	77.93	1700	2	14.0	.254	40	
Pecuaria	Flujo supercrítico (Walnut Gulch) Q= 3.34 m^3/s	46.86	1920	3	19.6	.123	30	Arenisca Conglomerado
Agrícola	Tipo H de 61 cm (2 ft) Q= 0.31 m^3/s	1.1	N.A.	N.A.	7.8	.464	40	Ignea extrusiva ácida
	Muestreador tipo Coshocton 30.5 cm (1 ft)							

[1]N.A. = no se aplica

un vertedor de tipo triangular de cresta gruesa en la parte alta de la cuenca, con un uso primordialmente forestal y un poco pecuario. En la parte media se tiene una cuenca de uso primordialmente pecuario, con un vertedor de flujo supercrítico (Walnut Gulch). En la parte baja se tiene un vertedor de tipo H y un muestreador de sedimentos de tipo Coshocton de 30.5 cm (1 ft) de diámetro. (Brakensiek, Osborn y Rawls 1979).

Los datos hidrométricos de estas cuencas a partir de 1985, servirán para plantear modelos de los flujos de energía, agua y nutrimentos que podrían validar la información que se obtendrá de los experimentos llevados a cabo a nivel de predio (micro), donde se aprovechará para integrar a los investigadores utilizando el sistema del productor.

Proyecto agua-suelo

Es claro que una de las manifestaciones del fenómeno de desertificación más graves es la erosión acelerada, que se produce cuando se combinan un mal manejo del suelo con las condiciones naturales adversas, tales como pendientes pronunciadas y lluvias de alta intensidad. La consecuencia directa de la erosión, es el detrimento en la productividad de los sistemas agropecuarios y forestales que se agrava en regiones de precipitación escasa al impedir el aprovechamiento de los escurrimientos superficiales.

El proyecto agua-suelo, acorde a lo anterior, se plantea como la base de todos los proyectos que se desarrollan en El Plateado y tienen como objetivos: 1) conocer los procesos físicos que rigen las relaciones agua-planta-suelo, 2) evaluar el efecto de las tecnologías tradicionales de manejo de suelos sobre dichas relaciones y 3) determinar las medidas preventivas y correctivas más adecuadas para la conservación y captación de suelo y agua, bajo las condiciones de "El Plateado".

Los subproyectos, dentro de este proyecto, obtendrán los siguientes parámetros; registro de variables hidrológicas que incluye hidrología y sedimentos, infiltración, datos climáticos, balance de agua, y nutrimentos. En relación al recurso suelo se incluye: mapeo intensivo, análisis físico químicos y clasificación por características agronómicas, así como aquellos componentes limitativos.

La parte del programa correspondiente a la aplicación de tecnología, consiste en trabajos de conservación del suelo a través de prácticas agronómicas, incremento de la cobertura , incorporación de esquilmos, control de cárcavas y efecto de la fertilización, mediante manejo agrícola a través de un uso eficiente de maquinaria y del agua de riego, y de la tracción animal.

Proyecto planta

Este tiene por objetivo, investigar el aprovechamiento máximo del recurso vegetal al incrementar el rendimiento de los cultivos, mejorar la condición del agostadero, conservar y explotar racionalmente el recurso forestal, domesticar plantas silvestres y formar una cubierta protectora al suelo contra los agentes erosivos.

Dentro de las acciones de investigación, se determinó realizar: inventario florístico, mapa de vegetación, estudios autoecológicos, exclusiones y evaluación de sistemas de uso de la vegetación y del suelo. La parte del proyecto correspondiente a la aplicación de tecnología consiste en: introducción de nuevas especies, variedades, y prácticas

agronómicas por áreas climatológicas, reforestación, sanidad vegetal y forestal, manejo de pastizales, combate de plantas indeseables y control de plagas y enfermedades.

Proyecto animal

La importancia de este proyecto de investigación queda evidenciada por el hecho de que el 70% de la superficie del área de estudio, se utiliza con fines pecuarios y buena parte de ésta se encuentra sobrepastoreada. El objetivo del proyecto es introducir formas de manejo que favorezcan la producción máxima sostenida sin deterioro del ecosistema, para lo cual, será necesario: primero, mejorar la condición del agostadero incrementando así la producción de forraje y posteriormente, determinar las prácticas de manejo de ganado óptimas y específicas para ese ecosistema.

Dentro de este proyecto de investigación, se planearon los siguientes aspectos: inventario ganadero, identificación de problemas, dieta de rumiantes, listado de fauna silvestre y cuantificación de poblaciones. Respecto a tecnología aplicada: sanidad animal, mejoramiento genético, reproducción,alimentación y la posible reintroducción de fauna silvestre de valor cinegenético práctico.

Dentro de este proyecto las investigaciones empiezan en 1987, por lo tanto no se presenta ningún resultado.

Proyecto socioeconómico

Para la realización del programa, se considera indispensable la participación activa de los productores en la definición de los proyectos de investigación para la generación de tecnología. El aspecto socioeconómico se define como la directriz de la investigación, ya que a través de él, serán planteados los problemas y necesidades reales a los productores para que entre éstos y los técnicos se definan las acciones a realizar.

El objetivo de este proyecto es: lograr la participación de los productores del área, en la formación, operación, evaluación y difusión de los resultados de los experimentos; definidos éstos con base en sus propias necesidades y en la protección y mejoramiento del ecosistema.

Los subproyectos de investigación quedan estructurados en cuatro etapas, la primera corresponde a la descripción del ambiente físico, biológico y social, la segunda y tercera etapas están dadas por la operación de los experimentos y la última representa la incorporación de los resultados en sistemas integrados de manejo.

Dentro de el área básica se enumeran las siguientes acciones: levantamiento socioeconómico y análisis, así como la identificación y priorización de problemas. En relación a la aplicación de tecnología se fomentará la organización de productores en sus formas más operativas y se buscará la coordinación entre estas organizaciones con instituciones de desarrollo, oficiales y privadas.

RESULTADOS

Aun cuando no existen recursos nacionales o internacionales etiquetados para este programa el Instituto Nacional de Investigaciones Forestales y Agropecuarias, no ha interrumpido sus trabajos; sin embargo, el hecho que se hayan derivado recursos humanos y financieros que corresponden a otros programas, ha limitado un avance acorde con lo que ha sido proyectado y consecuentemente, los resultados obtenidos no son lo suficiente abundantes como deberían ser en este período del proyecto.

Proyecto socioeconómico

La repercución y la relación con los productores, ha sido posible exclusivamente con aquellos que han mostrado interés en la manipulación de sus sistemas, y por otro lado, se ha buscado que tengan características personales de liderazgo en las acciones de producción que llevan a cabo en la comunidad. De esta forma, un primer paso ha sido la tipificación de las unidades de producción.

Para las partes alta y media se llevó a cabo un censo en el que participaron el total de productores, se encontró que la unidad típica de producción en la parte alta comprende una superficie bajo temporal de 5 ha, agostadero de 10 ha y bosque 10 ha. Los rendimientos medios de maíz son de 723 kg/ha y de frijol 166 kg/ha. Los productores que hacen rotación de cultivos son el 23% del total y el destino general de la producción es para el autoconsumo; el 68% de los propietarios utilizan el bosque en forma comunal y el 18% admiten que reciben asistencia técnica.

En cambio, en la parte media de la cuenca, la unidad de producción típica comprende 5 ha de temporal y 5 ha de agostadero, donde se obtienen rendimientos de maíz de 793 kg/ha y de frijol de 382 kg/ha. Solamente el 14% de los productores hace rotación de cultivos y algunos comercializan su cosecha; además, solo el 5% de los productores han recibido asistencia técnica.

Los problemas que los productores percibieron como limitativos de la producción fueron: el uso inadecuado y la poca profundidad del suelo, la baja disponibilidad del agua, la maleza y la condición pobre de los agostaderos.

La cuenca, tiene aproximadamente el 30% de la superficie dedicada a la agricultura, dentro de ésta existe una pequeña zona de agricultura de riego en los márgenes del Río de Juchipila de 325 ha.

En una encuesta efectuada a 108 productores temporaleros, se encontró que la superficie por propietario varía de 3 a 80 ha, distribuídas de la siguiente manera: el 22% tiene menos de 4 ha, el 34% tiene 4 ha, 30% tiene entre 5 y 6 ha y el 14% tiene superficies mayores de 9 ha. Asimismo, se

definió que el 35% de los productores se dedican a la agricultura de temporal, el 29% tiene un sistema de temporal con agostadero y el 12% se dedica a actividades netamente pecuarias. Los restantes (24%), se distribuyen en zonas de riego y sus combinaciones.

En cuanto a la agricultura de temporal la mayoría la dedican para el autoconsumo y generalmente, el tamaño de predio está relacionado con el nivel de insumo utilizado. El cultivo predominante es el maíz y en menor grado el frijol y el cacahuate; aproximadamente la mitad de los productores fertilizan su tierra y muy pocos utilizan agroquímicos. La producción media en agricultura de temporal es de 1 ton/ha.

Las características del sistema de explotación del agostadero son para venta comercial y consumo familiar. La superficie por productor fluctúa en la mayoría de los casos entre 40 y 90 ha, con una carga animal promedio de 2.8 ha por unidad animal, esto contrasta con las recomendaciones de 11.4 ha/u.a. para la parte alta y 7.05 ha/u.a. para la parte baja (COTECOCA 1980). El sistema de pastoreo es contínuo y extensivo y la mayoría de los productores ayudan al ganado en la época de secas con esquilmos de varios tipos.

Otro aspecto fundamental en la formación de lazos entre los productores e investigadores, ha sido el establecimiento de experimentos y acciones en general, entre éstas podemos contar con: el proyecto del INIFAP denominado El Productor Experimentador, establecimiento de bancos de germoplasma introducido, reforestación y ampliación de áreas de pastos introducidos.

En 1975, se planteó la necesidad de probar algunos materiales de maíz por los mismos productores en la parte alta, establecidos en cuatro comunidades, con la participación activa de los productores. Desafortunadamente, el temporal fue muy malo y los resultados desalentadores, ya que sólo se obtuvo rastrojo en una sola localidad con rendimientos de hasta 5.25 ton de MS/ha.

Por otro lado, se han establecido en varios sitios en la parte alta y media, colecciones de gramíneas para observar su adaptabilidad y producción. A su vez, a través de programas de Gobierno del Estado de Zacatecas, se establecieron en coordinación con productores, superficies semicomerciales de pastos introducidos como: Buffel Cenchrus ciliaris, llorón Eragrostis lehmanniana y banderita Bouteloua curtipendula a lo largo de toda la cuenca.

El interés por apoyar la producción forestal y alentar la reforestación nos ha permitido establecer tres lotes de introducción del pino plateado piñonero Pinus maxi-martinezii, con un total de 600 plantas, para definir los sitios con posibilidades de producir el piñón de alto valor comercial.

Estas acciones, hasta ahora han sido aisladas y de efecto limitado en la población, por esto se decidió obtener un apoyo más decidido teniendo personal que viviera directamente en las comunidades y que lograran ganar la confianza que los investigadores sólo han tenido aisladamente. A partir de 1987, se cuenta con un matrimonio capacitado en desarrollo rural y la medición de su consecuencia, así como también en hacer que los productores hagan suyos los resultados del proyecto.

Proyecto Agua-Suelo

En 1981, se excluyeron al pastoreo áreas representativas de los diferentes tipos de vegetación que se encuentran en la cuenca, para observar en ellas el efecto del descanso del pastoreo en la producción y composición del agostadero. En estas áreas protegidas del pastoreo, se estudió el efecto de la lluvia simulada sobre la infiltración y pérdida del suelo, y se compararon estos parámetros con los observados en áreas pastoreadas. Los resultados de esta investigación formaron parte de una tesis doctoral (Sánchez 1984).

Los sitios en estudio involucraron las principales comunidades vegetales existentes a través de la Cuenca Hidrológica, desde el bosque de encino, en la parte alta, hasta los matorrales espinosos, en la parte baja.

Los cambios sucesionales de los sitios influyeron significativamente en la tasa de infiltración. Lo anterior, fue demostrado por tasas de infiltración más altas, para tratamientos excluídos al pastoreo por tres años, comparado con tratamientos pastoreados (cuadro 2).

El sitio de pastizal con más bajo potencial para incrementar la tasa de infiltración, con un descanso de tres años, fue el sitio correspondien-

Cuadro 2.--Infiltración terminal media (cm/hr) entre sitios pastoreados y excluídos al pastoreo. INIFAP-Zacatecas-México.

Sitio	1982		1983	
	Pastoreado	Excluído	Pastoreado	Excluido
Matorral espinoso	1.67 b[1]	2.07 ab	1.63 b	2.00 bc
Selva baja caducifolia en lomeríos	1.46 b	1.37 b	1.89 b	2.65 bc
Selva baja caducifolia en ladera	2.01 a	2.44 a	1.75 b	3.30 a
Pastizal con encino	3.03 b	2.73 a	1.31 a	4.15 b
Area cultivada abandonada	1.94 b	2.50 a	2.71 a	3.04 b
Bosque de encino.	2.39 ab	1.21 b	2.02 ab	2.57 bc

[1]Las medias seguidas por la misma literal para cada columna no son significativamente diferentes (P<.05).

te a matorral espinoso. El mejor sitio fue el de pastizal con encino, observándose incrementos en la tasa de infiltración de 1.31 a 4.15 cm/hr, bajo condiciones de pastoreo y excluído al pastoreo a corto plazo, respectivamente.

Las variables de primera importancia para predecir la tasa de infiltración fueron microrelieve del suelo, mantillado orgánico, área desnuda y la cobertura de roca. Estas variables fueron diferentes para cada sitio estudiado, y se obtuvo una ecuación predictiva para cada sitio.

Los cambios sucesionales de los sitios también influyeron en la cantidad de sedimentos transportados por los escurrimientos superficiales. El sitio con más bajo potencial para reducir la cantidad de sedimentos en tres años de exclusión al pastoreo, fue el de selva baja caducifolia con _Ipomoea_ _sp_. y _Acacia_ _sp_. localizado en lomeríos de la parte baja de la cuenca. El sitio que mostró la mayor reducción en la cantidad de sedimentos transportados, fue el pastizal con encino, ubicado en la parte alta de la cuenca. Los sedimentos disminuyeron de 265 a 54 kg/ha, para pastoreado y excluído al pastoreo, respectivamente (cuadro 3).

Las variables de importancia primaria para predecir sedimentos fueron la cobertura foliar de pastos, la biomasa aérea de pastos, área basal total, microrelieve de suelo y cobertura de rocas.

La anterior información es de utilidad para definir guías de utilización de las especies presentes en un pastizal al conocer el grado de utilización del recurso y su repercusión en la conservación del recurso suelo-agua.

Cuadro 3.--Producción media de sedimentos (kg/ha) entre cada sitio para áreas pastoreadas y excluídas al pastoreo. INIFAP-Zacatecas-México.

Sitios	Pastoreado	Excluido
Matorral espinoso de _Prosopis_ y _Acacia_ en lomeríos.	549 a[1]A	514 a A
Selva baja caducifolia con _Bursera_ y _Acacia_ en lomeríos	241 a B	215 a B
Selva baja caducifolia con _Ipomoea_, _Bursera_ y _Eysenhardtia_ en ladera	170 a BC	121 b BC
Pastizal con _Quercus_	265 a B	54 b D
Area cultivada abandonada	128 a C	78 b CD
Bosque de _Quercus_	111 a C	77 b CD

[1]Las medias seguidas por la misma literal minúscula para cada sitio y para la misma literal mayúscula entre cada columna no son significativamente diferentes (P<.05).

Proyecto Planta

En 1982, se establecieron en la zona, experimentos sobre introducción y adaptación de variedades de mijo, se obtuvieron resultados satisfactorios con especies del género _Pennisetum_, tales como la variedad Millet-13 para forraje, y con el género _Setaria_, variedad PI-391634 para grano. Se iniciaron estudios tendientes a la domesticación del "varaduz" (_Eysenhardtia polystachia_), que es una arbustiva leguminosa nativa que tiene grandes posibilidades como planta forrajera que podría expanderse bajo manejo.

Dichos estudios, iniciaron con el conocimiento de la fenología de la planta, como resultado se observó que se dispone de 114 días para la utilización de esta arbustiva por los animales domésticos.

En 1983, se iniciaron los subproyectos: colección, introducción, evaluación y reproducción de germoplasma agrícola y forrajero, y prácticas agronómicas. Dentro del primero se obtuvieron los resultados que se muestran a continuación:

Cultivo	Sobresalientes	Rendimiento Grano (kg/ha)
Maíz	H-419	5,479
(riego)	AN-430	
Frijol	SIECHI	1,315
(temporal)	Pinto Fresnillo	1,303
Cacahuate	Guanajuato Español	481
(temporal)	Blanco del Río	436
Girasol	IS-7775	857
	Cernianka	719
Sorgo	IC/CI-2	5,088
Mijo	MBH-110	892
	IVS-P-77	788

La investigación en la línea planta, está también orientada a mejorar la condición del agostadero a través de prácticas de mejoramiento del pastizal. Como resultado sobre control químico de arbustivas indeseables, en la parte baja de la cuenca se logró hasta un 99 y 85% de mortandad para gatuño y huizache, hexazinone, en invierno y primavera, respectivamente.

Para apoyar la interpretación de la dinámica de la vegetación, y en especial la del pastizal, se han establecido seis exclusiones a través de las diversas comunidades presentes en la Cuenca. Los resultados más sobresalientes han sido las diferencias en respuesta al descanso y su relación casi directa con la tasa de infiltración media.

En sitios de bajo potencial, donde por causas aún no claramente conocidas, la colonización del suelo por gramíneas es muy lenta o nula, se ha encontrado un incremento muy bajo (0.07 cm/hr) de la tasa de infiltración, como es el caso de la exclusión Apulco en la parte baja. En cambio el sitio J. Amaro, tuvo una gran respuesta a la exclusión (3.55 cm/hr), cabe mencionar que éste es un sitio más mésico, con gran acumulación de hojarazca. Los

parámetros vegetales cobertura y cosecha en pie, mostraron ser más variables en función de la cantidad y la distribución de la lluvia.

PROYECCION

En forma resumida se ha presentado el proceso que se siguió para localizar y definir un escenario ecológico, que además se busca cambiarlo. El cambio obedece a las metas ambiciosas que se establecieron para hacer eficiente el proceso natural y sobre todo corregir el retroceso que se ocasionó en las últimas décadas por efecto de la acción del hombre que inclusive está poniendo en peligro la supervivencia del recurso.

En estos pocos años de experiencia, se han obtenido algunas conclusiones valiosas que se resumen así:

1. Cualquier línea de investigación que se desarrolle en esa región tiene perfecta cabida en el contexto de la cuenca hidrológica y de esta manera queda integrado y se facilita conocer las interacciones entre ellas.

2. Este no es un proyecto que deba llevar una sola institución, debe ser compartido entre varias y además multidisciplinario.

3. Los recursos humanos, financieros y materiales deben ser acordes y en balance con la magnitud del problema, de lo contrario la solución integral que se busca se ve muy lejana y que quizá imposible.

4. En países en vías de desarrollo, como es el caso de México, un proyecto como el presente no tendrá ninguna posibilidad de éxito sin la participación activa de los habitantes de la cuenca hidrológica. Cualquier solución a que se llegara no tendría ningún sentido sin pasar a través del filtro económico y social que es indispensable.

5. El período de duración de estos proyectos, aun teniendo todos los apoyos necesarios, requieren del factor tiempo y es así como los países desarrollados han concebido que estos proyectos deban estar dentro de un contexto a largo plazo, que está definido por esa característica y se abrevian LTER-Long Term Ecological Research (Strayer, (986).

6. Se aprendió también que un análisis profundo del concepto de integración de una cuenca nos indica que este enfoque sistémico que ha sido establecido a lo largo del flujo de agua, deberá substituir invariablemente a cualquier intento aislado de investigación que considere alguno de los recursos naturales que se quiera investigar en forma aislada.

7. Finalmente el convencimiento de este enfoque de investigación tiene muchas ventajas sobre los esfuerzos aislasionistas: obliga a establecer un sistema de comunicación y difusión clara de lo que se pretende a todos los actores que participan, desde los productores que tienen los papeles estelares, hasta los tomadores de decisiones de alto nivel cuya última palabra determina la existencia o ausencia del proyecto y desde luego, están los investigadores que obviamente deberán ser los más enterados.

Los siete puntos antes señalados son quizá la cosecha más importante que ha dado El Plateado. Se tiene un modelo científicamente viable y sitúa además en la realidad objetiva del productor. Por consiguiente se cree que está completo.

El concepto sistemático de manejo de una cuenca no se entiende fácilmente y a medida que no se entiende no se cree en él.

Es aquí donde se tiene una tarea difícil por delante, un verdadero reto, pero existe una esperanza.

AGRADECIMIENTOS

El proyecto indudablemente ha tenido otros investigadores trabajando en diferentes épocas, algunos de ellos son: Doroteo Caro Valderrama, Ramón Gutiérrez Luna, Alfonso Serna Pérez, Miguel A. Velázquez Valle, a todos ellos les reconocemos sus esfuerzos sin los cuales este proyecto no hubiese avanzado.

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Using Natural Desert Ecosystems as Models for Agroforestry: The Gray, Spiney Revolution[1]

Gary Paul Nabhan[2]

Abstract: Because groundwater and surface water resources are now overallocated in North American deserts, we must further consider rainfed food production based on multicropping native, adapted plants. The lifeform diversity and structural heterogeneity of desert plant communities can serve as models for agroforestry.

We are at a turning point in the history of food production in arid zones, and the much of desert forestry, applied ecology and agronomy work being done in Mexico and the U.S. today reflects this change in direction. We are changing from the resource management perspective which has dominated at least a century of desert development, during which human populations have increased beyond their capacity to obtain their food directly from arid, rainfed ecosystems.

Instead of supporting ourselves on the desert's intrinsic resources, we have relied on transported food imported from more humid zones. We have also dammed rivers and pumped underground water to irrigate moisture-loving food and forage crops. This transformation of the desert will attract about 850 million people to dry land regions around the world by the year 2000. Look at our desert cities--- Juarez, Phoenix, Mexicali, Torreon, Las Cruces, Monterrey, Las Vegas, Hermosillo and Tucson---- their apparent vitality would be not possible in its present condition without large supplies of groundwater or river water captured by large dams.

Yet our ability to continue to expand high-input food production is severely limited, especially in dry lands. There is already a worldwide scarcity of fresh, clean water, and that is why we are at a turning point. Groundwater aquifers are being rapidly depleted and contaminated. From this point in history, it it is probable that the area in American deserts irrigated by groundwater will decrease, not increase. Already, many groundwater-irrigated fields have been abandoned on tens, if not hundreds of thousands of hectares in the Costa de Hermosillo, La Laguna, the Ogallala aquifer in west Texas, and in Arizona's Cochise and Pinal counties.

Similarly, surface water supplies from rivers have already been over-allocated. As Donald Worster (1985) has pointed out, the last major dam projects in the United States have already come to pass. No new irrigation projects of any size have been approved in the last twenty years. Mexico is still planning some river irrigation projects, but in smaller and smaller watersheds. And much of our river water will go to urban growth, not to food production.

Thus, there is a great need for rainfed food production systems based on plants which require less water than do conventional crops derived from humid zones. In general, there is a global demand for low-input food production systems, for they have greater stability and less risk of failure than high input systems (Ehrenfeld 1987). I believe that desert agroforestry production and the domestication of wild desert adapted plants will help meet these demands, if they remain responsive to the local human communities and environments where they are initiated.

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[1]Paper presented at the Symposium on Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones [Tucson, Arizona, October 12-16, 1987].

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However, most agroforestry projects today use exotic species and are not well-integrated with the surrounding ecosystems. Agroforestry designs should use as their models the natural ecosystems of the region where they are to be placed, rather than conventional agronomic systems. In the Sonoran Desert, we can use the great diversity of plant adaptive strategies as the components of our agroforestry designs.

But what are the characteristics of desert ecosystems? Although low in species diversity, these ecosystems are high in genetic diversity and lifeform diversity as the studies presented in this conference have shown. Their dominant plants utilize multiple strategies for adapting to and tolerating abiotic stresses such as heat and drought. They are phenologically stimulated by rains of greater than 25-30 millimeters falling within a few hours during particular seasons. Tolerance to interspecific competition may be low, and this may account for the variability in the degree of structural heterogeneity that we find in different desert habitats. Yet we can use the most heterogeneous habitats as models for designing complex, more stable food systems that require few outside inputs. We can imagine an agroforestry system using numerous desert lifeforms, each placed in an appropriate microhabitat (Nabhan 1984).

But to design such a system, we must have excellent inventories of the desert vegetation types in each region, the useful plants within each type, and their microhabitat requirements. Several studies presented during this conference illustrate advances in accomplishing these kinds of inventories, from new systems to classifying vegetation to synecological studies of particular resource plants.

We must document not only the useful tree species, but economic plants of other lifeforms as well, as Heriberto Parra Hake, Wendy Hodgson, Robert Bye and Noe Meraz have suggested during this conference. We must identify if any of these useful plants are being overexploited as agaves are in some regions. Certain useful plants, such as *Panicum sonorum* are threatened with extinction in deserts. If we are ever to utilize them, we must first conserve these plants at risk, and rescue the remaining genetic diversity left in their gene pools.

Several studies presented during this conference illustrated the use of germplasm nurseries, or living gene banks, for conserving and evaluating desert species for forestry projects. Both the U.S. and Mexico need to invest more in the maintenance of long-term germplasm nurseries of desert crops and agroforestry species, for conventional plant materials centers in more humid zones do not serve us well. The INIFAP halophyte nursery for seed production at Rancho La Sauceda in Coahuila is an excellent example of a gene bank for underexploited species. At Native Seeds/SEARCH gardens nearby the conference site in Tucson, numerous desert-adapted native crops and their wild relatives are being grown for seed increases, to share for free with indigenous communities and researchers in the U.S. and Mexico. At the Gentry Agroecology Project of the Desert Botanical Garden in Phoenix, we are growing more than fifty species native to the Sonoran and Chihuahuan Deserts, each of which can provide multiple products, such as food, spices, medicines and fuelwood.

At the same time we are conserving and increasing the seed supplies of scarce desert resource plants, we should evaluate their environmental tolerances and establishment requirements.

It may be that some of these species cannot be used in reforestation efforts unless nurse plants, mycorrhizal associates, or supplemental moisture are provided to them. Too many new crop projects have already failed because rural development workers believed that *low input* plants required *no inputs* whatsoever. We need to determine whether the use of microbial inocula and runoff microcatchments can increase our successes.

As we are determining through the FLORUTIL project coordinated by the Desert Botanical Garden and the Universidad Autonoma de Tamaulipas, there are numerous valuable desert plants that are threatened with extinction. We have three options for managing them: 1) protecting remaining populations from overharvest and other threats, to allow eventual recuperation; 2) reforesting their former range with these plants to allow for a managed wild harvest in the future; or 3) collecting seeds for *ex situ* conservation, propagation, and perhaps even commercial cultivation.

But what happens once we have identified particular wild plant genetic resources that do well with few external inputs, and we begin to propagate or cultivate them in agroforestry projects? If we domesticate these wild plants for their valuable products, how does this effect the small producer who has been gathering these products directly from the wild? Is he eliminated from the market because his production and quality is low relative to that of subsidized projects? Is he allowed to draw on the reforested populations, so that his production increases? Do new harvesting and processing methods improve the quality of his product and reduce the waste and the pressure on the plant populations?

If our forestry management efforts are to help rural desert dwellers, many of whom have inadequate sources of income, we must ask such questions when we begin designing our projects. Local communities must be asked about their needs, and should be considered partners in the management, conservation and development of local plant resources. Conference participants documented several examples of this community involvement already taking place, from Tamaulipas, to the Altiplano, to the Sierra Madre Occidental, to Indian reservations in the Sonoran Desert.

Finally, it is clear that we have past the phase of being enamored by single "miracle crops," whether they be Eucalyptus, Leucaena, Simmondsia, or Parthenium. None of these plants are panaceas to all of our problems in North American deserts. We now know that many of the so-called miracle crops develop new management problems when cultivated intensively in monoculture (Alcorn, Mihail and Orum 1986). Instead, investigators are evaluating polyculture cropping and agroforestry systems in which several useful plants are intercropped (Altieri 1983). The integrated modules, developed in the Chihuahuan Desert, the Altiplano and the Baja California peninsula by INIFAP investigators, are excellent examples of multicropped, rainfed food and forage production systems.

The approaches to desert food production presented at this conference are appreciably different from those labelled as the Green Revolution, in which one or two widely-adapted, high-yielding crop varieties are grown with high inputs of water, pesticides and fertilizers.

We might instead label this newly emerging approach to desert food production the Gray, Spiney Revolution. It draws upon native plants with intrinsic adaptations to heat and drought such as gray pubescence on their leaves, or thorns and spines to reduce predation, heat load, and radiation damage. But it is also a Revolution which respects the integrity of natural desert ecosystems as a whole, and draws upon the indigenous knowledge of desert-dwelling cultures. Hopefully, it will lead us to a sustainable form of food production that will not deplete the soil, the biotic resources or the human communities of North American deserts.

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BALANCE HIDRICO EN MAIZ DE TEMPORAL EN AGUASCALIENTES, MEXICO[1]

Miguel Angel Martinez Gamiño[2]

Resumen. Se cuantificaron los escurrimientos superficiales, erosión hídrica y su control, evapotranspiración y rendimiento del maíz de temporal. Una cobertura de paja, 5 ton/ha, redujo 33 o/o los escurrimientos superficiales y 80 o/o la erosión hídrica. La sequía durante el llenado de grano afectó el rendimiento en más del 100 o/o.

INTRODUCCION

En Aguascalientes, el factor principal que limita la producción de maíz de temporal es la escasez e irregularidad de las lluvias, lo cual ocasiona periodos con déficit hídrico para la planta, los cuales generalmente coinciden con la floración y el llenado de grano. En la actualidad es necesario un uso más adecuado de los recursos fundamentales en la producción agrícola como en este caso el del agua. Sin embargo, no se tiene una cuantificación precisa de los fenómenos que giran en torno al ciclo hidrológico y en especial aquellos que ocurren en el sistema agua–suelo–planta–atmósfera, donde el balance hídrico permite una cuantificación de las relaciones entre sus componentes.

El objetivo del presente trabajo fue cuantificar los escurrimientos superficiales, erosión hídrica, evapotranspiración y rendimiento del maíz de temporal.

REVISION DE LITERATURA

El balance hídrico es definido como una aplicación de la Ley de Conservación de la Materia y en este caso, del agua en el sistema suelo–planta–atmósfera, donde la cantidad de agua almacenada en un volumen dado de suelo debe ser igual a las diferencias entre los ingresos y egresos de agua, como lo consignó Norero (1984), quien además consideró la siguiente expresión algebráica.

$$Lf = Li + P - e - E - Ep - I$$

donde:

Lf = Lámina de agua retenida en un volumen dado de suelo al finalizar un periodo de "t" días;

Li = Lámina de agua contenida en ese volumen de suelo al iniciarse el periodo de "t" días:

P = Agua aplicada a la superficie del suelo durante el periodo "t", agua de precipitación, de riego o ambas;

e = Agua que sale del suelo por escurrimiento superficial;

E = Agua evaporada por la superficie durante el periodo "t",

Ep = Agua traspirada por la vegetación durante "t", y

I = Agua de percolación durante "t".

Los métodos para cuantificar el balance hídrico pueden ser directos o indirectos. Los primeros se basan en medir bajo condiciones reales los componentes del ciclo hidrológico por separado y los indirectos son aquellos que emplean en sus análisis datos meteorológicos, además de las características de suelo y planta.

Métodos directos

Dado lo específico del balance hídrico, National Academy of Sciences (1974), señaló que fue necesario considerar:

a) Suelo. Especialmente características de retención, escurrimiento e infiltración del agua;

b) Topografía. Pendiente del área y dirección de arroyos;

c) Precipitación. Total, frecuencia e intensidad;

d) Cultivos. Necesidades hídricas durante el ciclo vegetativo;

e) Otros factores climáticos como: viento, temperatura, luminosidad, etc.

Por su parte Lombardi (1976), describió un sistema para determinar el escurrimiento superficial en estudios de balance hídrico, mediante parcelas de 20 m de largo por un metro de ancho con un colector con capacidad de 1,000 litros en la parte baja. Con frijol, algodón, mijo y soya, reportó para los dos primeros cultivos una pérdida de agua por escurrimientos del 13 o/o del total de las lluvias y en el caso de mijo y soya fue de 5 y 7 o/o respectivamente. Consideró a este método como aceptable para determinar la evapotranspiración real de los cultivos a nivel de campo.

[1] Artículo presentado en el Simposium de Estrategias de Clasificación y Manejo de la Vegetación Silvestre para la Producción de Alimentos en Zonas Aridas, en Tucson, Arizona, Octubre 12–16, 1987.

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El Colegio de Postgraduados (1977), señaló un método similar por medio de lotes de escurrimientos de 2 m de ancho por 10 m de largo, con un depósito graduado en litros en la parte baja, lo cual permitió cuantificar el agua que se perdió por escorrentía y la que se retuvo en el suelo.

Dada la variación del área experimental en trabajos de balance hídrico, Ortiz (1982), consideró que el tamaño del área experimental estará en función de los objetivos a estudiar.

Métodos indirectos

Son una representación matemática de las relaciones en el sistema agua–suelo–planta–atmósfera. Por su naturaleza permiten predecir los componentes del ciclo hidrológico a nivel macro y micro.

La literatura reporta un gran número de dichos modelos, como los señalados por Norero (1984) y Palacios (1978), sin embargo éstos estan encaminados más a zonas de riego que a temporal. Por su parte Villalpando (1984) citó un método sugerido por la FAO para realizar un balance hídrico en condiciones de temporal en periodos mensuales de 10 días, donde se involucran datos de precipitación; evapotranspiración potencial (ETP), la cual fue definida como el producto de la evaporación de un tanque tipo "A" multiplicado por 0.75 como factor de ajuste y así obtener la cantidad de agua necesaria para que el cultivo no presente déficit hídrico; un coeficiente de desarrollo del cultivo "Kc" por etapa fenológica; la evapotranspiración real (ETR) obtenida como el producto del valor de la ETP y el "Kc"; por último se considera la humedad residual en el suelo en función de la capacidad de almacenamiento de agua por el suelo y que se obtiene al restar el valor de ETR al de la precipitación.

MATERIALES Y METODOS

El trabajo se realizó durante 1980 y 1981 en el Campo Agrícola Experimental Auxiliar de Sandovales, en el estado de Aguascalientes (22^{o} 09′ LN y 102^{o} 18′ LW) con una altitud de 2000 msnm. Su clima se define como BS_1 KW (w), que corresponde a un clima semi–seco, con lluvias en verano y escasas a lo largo del año, temperatura media anual entre 12 a $18^{o}C$, según García (1973). La precipitación varía de 182 y 486 mm, con una media de 363 mm en un periodo de 10 años (1973 a 1982). Los suelos son del tipo Planosol Eútrico, textura migajón arcillo arenoso y duripán o tepetate a menos de 50 cm de profundidad y pendiente del 6 o/o.

Se utilizó la variedad VS–202, con una densidad de siembra de 12 kg/ha. El suelo se barbechó, rastreó y surcó en mayo de cada año de estudio, se fertilizó con el tratamiento 40–40–00; como fuente de nitrógeno se usó nitrato de amonio y de fósforo, superfosfato de calcio simple. Las parcelas fueron de ocho surcos a 0.76 m entre sí por 30 m de largo, en la parte central se tuvo una área de 2 x 10 m delimitadas con láminas; en la parte baja se colocó un depósito con capacidad de 600 litros para medir escurrimientos y estimar la erosión hídrica. La humedad del suelo se determinó por el método gravimétrico en dos profundidades: 0 a 25 y 25 a 50 cm, en muestreos realizados dos veces por semana.

Una vez delimitadas las dos parcelas a una de ellas se le esparcieron 5 ton/ha de rastrojo seco de maíz. Se siguió el procedimiento de la FAO, señalado por Villalpando (1984), pero considerando la evapotranspiración actual (ETA) en base a la humedad del suelo. El análisis se dividió en cuatro etapas fenológicas de acuerdo a Jugenheimer (1981), las cuales fueron:

Etapa I. Vegetativa, que comprende desde la generación hasta la diferenciación de órganos reproductores.

Etapa II. Transición hasta antes de floración.

Etapa III. Reproductiva, abarca el periodo de floración.

Etapa IV. Formación y llenado de grano hasta llegar a madurez fisiológica.

RESULTADOS Y DISCUSION

Balance hídrico en 1980

El Balance hídrico para 1980 en maíz de temporal indicó que dicho cultivo tuvo un déficit hídrico de 232.3 mm en su ciclo vegetativo que abarcó del 24 de julio, fecha de la siembra al 20 de noviembre.

En el Cuadro 1 se reportan los valores obtenidos en cada etapa fenológica del maíz sin cobertura de rastrojo. Para la etapa I o vegetativa se registraron 177.1 mm de precipitación, que representaron el 70 o/o del total, situación que generó se obtuviera un balance positivo es decir las necesidades hídricas del cultivo sí fueron cubiertas sin restricción, aun cuando se perdieron por escurrimientos 52.2 mm, lo que pone de manifiesto una mala distribución de la precipitación con respecto a las necesidades del cultivo, pues a partir de la etapa II o vegetativa la precipitación cada vez fue menor y en cambio las necesidades hídricas del maíz fueron en aumento, hasta cuantificar en el llenado de grano un déficit hídrico de 112.3 mm lo cual ocasionó que el rendimiento de grano fuera de solo 125 kg/ha y el de rastrojo 500 kg/ha.

En el Cuadro 2 se listan los valores obtenidos del balance hídrico con cobertura de rastrojo de maíz donde se destaca que dicha cubierta al suelo disminuyó un 25 o/o los escurrimientos registrados sin cobertura, situación que favoreció una mayor infiltración del agua en el suelo y por lo tanto el cultivo tuvo más disponibilidad de agua en el suelo, lo que se reflejó en los valores de la ETA, dado que se obtuvieron con base en la humedad del suelo.

En total, los valores de la ETA se incrementaron en un 23 o/o con el uso de la cobertura con rastrojo de maíz. No obstante dicho efecto positivo en la retención de humedad del suelo, no fue relevante en el rendimiento de grano dado que éste fue de 120 kg/ha, similar al testigo y en rastrojo se obtuvieron 850 kg/ha.

Cuadro 1.— — Evapotranspiración actual, real y potencial (ETA, ETR y ETP) para maíz de temporal sin cobertura de rastrojo en Sandovales, Aguascalientes, México, 1980.

Etapa Fenológica	Prec.	Escurr.	ETA	ETR	ETP	ETA-ETR
	....		(mm)	....		
I	177.1	52.2	55.0	52.0	130.0	3.0
II	46.0	10.7	79.9	122.5	153.1	-42.6
III	17.0		13.7	94.1	94.1	-80.4
IV	12.0		7.9	120.2	150.2	-112.3
TOTAL	252.1	62.9	156.5	388.8	527.4	-232.3

Cuadro 2.— — Evapotranspiración actual, real y potencial (ETA, ETR y ETP) para maíz de temporal con cobertura de rastrojo en Sandovales, Aguascalientes, México, 1980.

Etapa Fenológica	Prec.	Escurr.	ETA	ETR	ETP	ETA-ETR
	....		(mm)	....		
I	177.1	40.8	58.9	52.0	130.0	6.9
II	46.0	6.5	97.0	122.5	153.1	-25.5
III	17.0		17.7	94.1	94.1	-76.4
IV	12.0		19.2	120.2	150.2	-101.0
TOTAL	252.1	47.3	192.8	388.8	527.4	-196.0

Balance hídrico en 1981

En 1981 el ciclo del maíz fue del 20 de julio al 19 de noviembre. En los Cuadros 3 y 4 se reportan los valores del balance hídrico obtenidos con y sin cobertura de rastrojo. En ambos casos el balance general resultó negativo con 283.9 y 257.8 mm respectivamente.

Cuadro 3. — — Evapotranspiración actual, real y potencial (ETA, ETR y ETP) para maíz de temporal sin cobertura de rastrojo en Sandovales, Aguascalientes, México, 1981.

Etapa Fenológica	Prec.	Escurr.	ETA	ETR	ETP	ETA-ETR
	....		(mm)	....		
I	34.8	14.7	12.9	51.6	129.1	-38.7
II	34.4		54.2	112.2	140.1	-58.0
III	15.5	7.3	6.4	67.9	67.9	-61.5
IV	8.9		2.9	128.6	160.7	-125.7
TOTAL	93.6	22.0	76.4	360.3	497.8	-283.9

Cuadro 4. — — Evapotranspiración actual, real y potencial (ETA, ETR y ETP) para maíz de temporal con cobertura de rastrojo en Sandovales, Aguascalientes, México, 1981.

Etapa Fenológica	Prec.	Escurr.	ETA	ETR	ETP	ETA-ETR
	....		(mm)	....		
I	34.8	6.7	22.4	51.6	129.1	-29.2
II	34.4		56.5	112.2	140.1	-55.7
III	15.5	3.2	7.7	67.9	67.9	-60.2
IV	8.9		15.9	128.6	160.7	-112.7
TOTAL	93.6	9.9	102.5	360.3	497.8	-257.8

La distribución de la precipitación al igual que en 1980 fue más abundante al inicio del ciclo del cultivo y durante el llenado de grano se registró el menor volumen por lo que se obtuvo un déficit hídrico donde sólo se cubrió un 2 o/o de las necesidades reales del cultivo (ETR). En dicho año el rendimiento de grano fue nulo.

Por su parte el tratamiento con cobertura nuevamente disminuyó los escurrimientos en 55 o/o por lo que se incrementó la infiltración del agua en el suelo, lo que permitió que el valor de la ETA con cobertura fuera 6.33 o/o mayor que sin cobertura. Dicho efecto no impidió que el rendimiento de grano fuera nulo.

Erosión hídrica

Las pérdidas de suelo por erosión hídrica en 1980 fueron de 12.63 y 2.66 ton/ha sin y con cobertura de rastrojo, respectivamente. En 1981 la erosión hídrica fue de 16.87 contra 9.05 ton/ha respectivamente. Lo anterior pone de manifiesto lo señalado por Winter (1977) en el sentido de que una cobertura de suelo con rastrojo disminuye la pérdida de suelo pues lo protege de la energía erosiva de la lluvia y al mismo tiempo incrementa la infiltración del agua en el suelo.

CONCLUSIONES

1.—Por la distribución de las lluvias, la etapa del llenado de grano fue la más afectada por un déficit hídrico.

2.—El efecto de la cobertura de rastrojo permitió disminuir la erosión hídrica en un 65 o/o y los escurrimientos en un 33 o/o en promedio.

3.—Resaltó la necesidad de opciones que permitan conservar la humedad del suelo más tiempo para aprovechar las lluvias de inicio del ciclo.

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ENSAYO DE OCHO CLONES DE NOPAL TUNERO EN AGUASCALIENTES, MEXICO[1]

Francisco Gutierrez Acosta[2]

Resumen. Se evaluaron ocho clones de nopal tunero en base a características de la planta y el fruto. No se encontró diferencias estadísticas entre los clones, y la producción en promedio de cinco años evaluados, de tuna por planta fue de 16.7 a 14.4 ton/ha. con un porcentaje de parte comestible del 63.3% del lóculo.

INTRODUCCION

El nopal es una planta importante para los habitantes de las zonas áridas y semiáridas, ya que se le puede usar directamente en la alimentación humana por sus frutos llamados tunas y los tallos tiernos como verdura. En Aguascalientes el nopal se encuentra prácticamente distribuido en todo el estado, sin embargo generalmente la población es escasa tendiendo a aumentar hacia la parte norte y noreste.

El objetivo del presente trabajo fue el de identificar los clones sobresalientes en cuanto a la producción de tuna de buen tamaño y calidad.

REVISION DE LITERATURA

Las cactáceas, son autóctonas del Continente Americano, en el que se les encuentra distribuidas desde el Canadá hasta la Argentina. México, por sus peculiares condiciones de latitud, topografía y clima es el país que alberga, posiblemente, la mayor cantidad de especies, Bravo (1978). En México están representados dos sub-géneros de *Opuntia* que son *Cylindropuntia* y *Platyopuntia*, Bravo (1937), citado por Barrientos y Brauer(1965). Rojas (1961) reporta que el nopal tunero fue bien conocido y empleado por los antiguos mexicanos. Los nahoas denominaban "nochtli" o "nopalli" a las cactáceas de tallos aplanados, añadiendo al radical "nochtli" uno o varios términos que precisaban la clase: "iztacnochtli" (de fruto blanco); "coznochtli" (de fruto amarillo); "xoconochtli" (con fruto ácido) y muchos otros que el habla común ha modificado. Barrientos y Brauer (1965) indican que las especies tuneras son principalmente: *Opuntia amyclaea* (blanca), *Opuntia megacanta* (amarilla), *Opuntia streptacantha* (cardón), *Opuntia ficus indica* (de castilla), *Opuntia robusta* (tapón) y *Opuntia hyptiacantha* (memela). Cruz (1980) establece la caracterización y determina las más sobresalientes en base a: producción de fruta, período de cosecha, grados brix en frutos y peso del fruto. Moreno (1962) indica que para realizar la caracterización de nopal de tuna, se debe basar en: altura de la planta, edad aproximada, largo, ancho y espesor de las pencas, forma y tamaño de las espinas, areólas, gloquidios, fecha de iniciación de brotes vegetativos y otros. Peralta (1983), al estudiar la caracterización de formas de nopal tunero, observó las características de la planta: vigor de la planta, sanidad y plantas en plena producción. Como también las características del fruto; tamaño, grosor de la cáscara, posición de la cicatriz floral en el receptáculo, número de semillas normales y abortivas y contenido de sólidos solubles totales.

Cruz (1980) al trabajar con clones de Copenas encontró que el peso promedio del fruto fue de 123.3 a 95.3 g y para los grados brix de 12.5 a 12.3. Alvarado (1978) observó un valor para grados brix de 15.5 a los 120 días después del amarre del fruto. Robles (1985) encontró que a los 126 días después de la floración fue de 13.84 grados brix. Delgado (1985) citado por Robles (1986) reporta que los sólidos solubles totales oscila entre 9.4 a 16.49. Peralta (1983) al estudiar 14 selecciones de nopal tunero encontró una variación de 16.9 a 13.8 grados brix.

MATERIALES Y METODOS

Este experimento se estableció en 1972 y la evaluación de producción fue de 1982 a 1986, en el Campo Agrícola Experimental Auxiliar de Sandovales, en el estado de Aguascalientes (22º09' LN y 102º18' LW) con una altitud de 2000 msnm. Su clima se define como BS_1 KW (m) que corresponde

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a un clima semi-seco, con lluvias en verano y escasas a lo largo del año, temperatura media anual entre 12 a 18°C, según García (1973). La precipitación varía de 182 y 486 mm; con una media de 363 mm en un período de 10 años (1973 a 1982). Los suelos son del tipo planosol Eútrico, textura migajón arcillo-arenoso y durián o tepetate a menos de 50 cm de profundidad y pendiente del 6%.

Se utilizó un diseño de bloques al azar con cinco repeticiones, parcela experimental de cuatro plantas y un distanciamiento de 4m entre líneas y 3m entre plantas. Los ocho clones evaluados fueron: Copena 1, Copena12, Copena 13, Copena 14, Copena 15, Copena 16, Copena 17 y Copena 18.

Las variables evaluadas son: altura de la planta, número de cladodios por planta, número y peso del fruto, rendimiento kg/pta, diámetro y grados brix del fruto. Además a una muestra de 10 frutos por clón, se le observó lo siguiente: peso del lóculo y cáscara, número de semillas normales y abortivas, y peso de semillas normales y abortivas.

RESULTADOS Y DISCUSION

Producción de tuna por planta

La producción de tuna por planta para los cinco años observados de los ocho clones evaluados, en promedio fue de 20.1 ton/ha para la Copena 16 y de 14.4 ton/ha para la Copena 17. Siendo ésta aceptable si se considera la producción regional de 6 ton/ha, (Cuadro 1).

En el Cuadro 2 se presenta el análisis de variación para la producción de tuna por planta, y no se identificó diferencias estadísticas entre los ocho clones evaluados, ya que se encontró la misma respuesta del material a las condiciones del lugar. En base a esto se puede asumir que no hay variación fenotípica entre los ocho clones evaluados.

Cuadro 1.- - Información de los años de producción en promedio de kg de tuna por planta. CIFAP Aguascalientes, INIFAP, SARH, México, 1986.

Material	1982	1983	1984	1985	1986	$\bar{X}$	Ton/ha[1]
C- 1	1.5	38.2	9.3	29.4	13.4	18.3	15.2
C-12	3.9	43.8	10.6	27.7	13.7	19.9	16.5
C-13	2.6	42.7	6.6	26.9	13.3	18.4	15.3
C-14	2.7	49.0	5.8	28.5	13.9	19.9	16.5
C-15	2.9	42.8	8.2	29.3	15.1	19.6	16.3
C-16	3.1	46.8	7.1	29.5	14.4	20.1	16.7
C-17	2.1	39.1	6.7	26.0	13.3	17.4	14.4
C-18	1.8	46.0	6.7	26.5	12.4	18.6	15.4

1 Se consideró 833 pl/ha.

Cuadro 2.- - Análisis de variación para la producción en promedio de kg de tuna, por planta CIFAP-Aguascalientes, INIFAP, SARH, México, 1986.

Factor de Variación	Grados de Libertad	1982	1983	1984	1985	1986
Bloques	4	9.08	49.93	128.83	28.26	14.28
Tratamientos	7	2.94 NS	68.54 NS	13.12 NS	10.08 NS	3.25 NS
Error Exp.	28	1.99	70.16	8.01	38.62	14.61
T o t a l	39					
C.V.		56%	19%	37%	22%	27%

Peso del fruto

El peso del fruto de los ocho clones evaluados, para 1986, fue de 127.6 gr para la Copena 12 a 87.3 gr para la Copena 15. Estos valores son parecidos a los que obtuvo Cruz (1980) con los mismos materiales, (Cuadro 3).

Parte comestible del fruto

El porcentaje de la parte comestible de la tuna, de los ocho clones evaluados para 1986, fue de, 65.6% para la Copena 17 a 59.5% para la Copena 12. Siendo esta relación aceptable ya que representa mayor porcentaje para el lóculo (parte comestible) en comparación con la cáscara que fue de, 34.1% a 33.5% respectivamente para los clones antes mencionados (Cuadro 3).

Grados brix del fruto

Los Grados brix (sólidos solubles totales), observados del fruto, de los ocho clones evaluados para 1986, fue de 16.0 para la Copena 17 y Copena 1 a 14.7 para la Copena 16. Esta información coincide con lo reportado por Robles (1986) y Peralta (1983), (Cuadro 3).

Cuadro 3.- - Características del fruto. CIFAP-Aguascalientes, INIFAP, SARH, México, 1986.

Material	Peso del Fruto gr	% Peso del fruto	% Peso de Cáscara	Grados brix
Copena 1	112.4	63.5	36.5	16.0
Copena 12	127.6	59.5	33.5	14.8
Copena 13	125.6	63.2	36.5	15.0
Copena 14	95.5	61.1	39.5	15.0
Copena 15	87.3	61.6	37.9	15.5
Copena 16	100.0	60.1	39.9	14.7
Copena 17	103.2	65.6	34.1	16.0
Copena 18	110.1	61.0	38.8	15.7

Epoca de cosecha

La época de cosecha de los ocho clones evaluados fue de los primeros días de julio a los primeros días de agosto, en los cinco años observados. Esto representa una ventaja ya que por lo general en la región se cosecha la tuna del 15 de agosto a septiembre.

CONCLUSIONES

1. Los ocho clones de nopal tunero, se comportaron igual en el lugar que se evaluaron.

2. La producción fue aceptable de 20.1 a 14.4 ton/ha si la comparamos con la regional de 6 ton/ha.

3. El porcentaje de parte comestible 61.9% de la tuna de estos clones es aceptable ya que la cáscara representa menor porcentaje 37.0% del peso del fruto.

4. La época de cosecha de los ocho clones en julio, representa una ventaja en comparación con el material que cosecha en agosto y septiembre, actualmente el productor.

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UN SISTEMA DE CAPTACION Y APPROVECHAMIENTO DE AGUA DE LLUVIA, COMO ALTERNATIVA PARA LA PRODUCCION AGRICOLA EN TEMPORAL DEFICIENTE[1]

Ernesto Martinez Meza[2]

Resumen. En Aguascalientes, México se desarrolló el presente trabajo, cuyo objetivo fue captar y redistribuir agua de lluvia, irrigando suplementariamente maíz, frijol y girasol de temporal. Los resultados de rendimiento de grano mostraron incrementos del orden del 386, 312 y 576% respectivamente; el forraje de maíz aumentó 327%. En el aspecto económico los ingresos netos fueron superiores en lo irrigado.

INTRODUCCION

El agua es uno de los recursos naturales más importantes; pero a la vez, uno de los más limitantes para la producción agrícola en las áreas de temporal de regiones semiáridas; como el el caso de la región denominada El Llano en Aguascalientes, México, en donde la lluvia es escasa y errática. En esta zona la precipitación media anual es de 350mm, con una distribución mala para la producción agrícola, pues normalmente se presentan periodos de sequía en las etapas de floración y llenado de grano, que como es conocido son las etapas más críticas para la mayoría de los cultivos en lo que se refiere a sus necesidades de humedad; consecuentemente, año con año los rendimientos disminuyen entre un 60 y 90% dependiendo de lo drástico de la sequía.

Los objetivos de este trabajo fueron evaluar una tecnología de producción de grano y forraje, basada en la captación y redistribución de agua de lluvia, como riego suplementario en la época de mayor demanda en los cultivos de maíz, frijol y girasol. Asimismo conocer el potencíal económico del sistema en función de los rendimientos obtenidos.

Gaddes (1970) define el término captación de agua de lluvia como la colecta y almacenamiento de agua en el campo, de escurrimientos superficiales y su uso posterior en irrigación de cultivos.

Turrent (1975) menciona que uno de los factores incontrolables de la producción en temporales críticos es la lluvia.

Velazco (1974) señala que en diferentes regiones del mundo, donde la lluvia es escasa y errática, y además se carece de infraestructura hidráulica se capta y almacena agua de lluvia para disponer de ella en las épocas más secas del año.

Anaya (1976) propuso como alternativa para un mejor aprovechamiento del agua de lluvia en zonas de temporal deficiente, captarla en pequeños bordos y aprovecharla en riego suplementario de cultivos.

Evenari et al (1971) señalan que los sistemas de captación de agua de lluvia, se desarrollaron hace aproximadamente 4000 años, por los habitantes del desierto del Negev en Israel, en donde conducían el agua captada en la laderas, hacia los valles para irrigar sus cultivos o almacenarla en cisternas para consumo humano y animal.

Krantz et al (1978) reportaron que los sistemas de producción en el trópico semiárido, basados en la captación de agua en pequeños tanques, haran más efectivo el uso de agua de lluvia por la posibilidad de riego suplementario, la reducción del riego y el aumento en el rendimiento de los cultivos.

MATERIALES Y METODOS

El trabajo se dearrolló durante 1986 en Sandovales, Aguascalientes, México. La fecha de siembra fue el 1º de julio para el frijol y el 2 de julio para maíz y girasol. El trabajo se hizo con maquinaria y las densidades de siembra fueron 12, 40 y 6 kg/ha para maíz, frijol y girasol respectivamente.

Las variedades utilizadas fueron: maíz: H-204; frijol: Bayo Madero y girasol: victoria. Todos los cultivos se fertilizaron con el tratamiento 40-40-00 aplicados a la siembra.

Los tratamientos estudiados en cada cultivo fueron: 1) temporal y 11) temporal auxiliado.

Se utilizó un diseño de parcelas apareadas distribuidas en el campo en franjas. La superficie total experimental fue de 1.824 ha. La precipitación durante el periodo junio-octubre fue de 526 mm y el

[1] Documento preparado para el symposium Estrategias de clasificación y manejo de vegetación silvestre para la producción de alimentos en zonas áridas. Tucson, Arizona, octubre 12-16, 1987.

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volumen calculado de agua captada fue de 7300 m^3 aproximadamente. La lámina total aplicada fue de 10 cm distribuida en dos auxilios. (Cuadro 1)

Cuadro 1. Intervalo entre los riegos de auxilio (días) a partir de la fecha de siembra en los cultivos del sistema. Sandovales, Aguascalientes, México. 1986.

Cultivo	1º auxilio	Días de Intervalo	2º aux.	Días de Intervalo
Maíz	14 agosto	42	30-ago.	16
Frijol	12 agosto	42	27-ago.	15
Girasol	12 agosto	41	28-ago.	16

El rendimiento de grano y de forraje se calculó con base en muestreos para cada tratamiento; se tomaron al azar surcos de 10 m de longitud para maíz y girasol, y de 5 m en frijol. El rendimiento se ajustó a kg/ha. El número de muestras en total para frijol y girasol fue de 15 por tratamiento y de 20 para maíz. La época en que se muestreó fue en madurez fisiológica para grano y en estado lechoso-masoso para forraje de maíz.

El análisis estadístico de los rendimientos se hizo por el método de t student para una $\alpha = 0.05$.

RESULTADOS Y DISCUSION

El criterio, con respecto al intervalo en días, para la aplicación de los riegos suplementarios a partir de la fecha de siembra fue el siguiente: aplicar primer riego cuando los cultivos estuvieran en floración y el segundo en llenado de grano. Sin embargo, estas fechas se modificaron, ya que cuando los cultivos se encontraban en una época de desarrollo vegetativo, se presentó una sequía de alrededor de 40 días, por lo que el primer suplemento de riego se aplico 22, 12 y 26 días antes de la floración de maíz, frijol y girasol respectivamente, y el segundo en floración, lo cual ocurrió a los 64, 54 y 67 días para los cultivos en el orden mencionado anteriormente. Se considera que esta modificación, no afectó considerablemente los rendimientos, ya que los resultados así lo confirmaron; por el contrario, esta información es importante para trabajos posteriores.

El análisis estadístico de las medias de rendimiento de grano y forraje de los cultivos bajo estudio, nos permite observar que el tratamiento de temporal auxiliado resultó estadísticamente superior en todos los casos, obteniéndose incrementos de 386, 312 y 576% para maíz, frijol y girasol respectivamente, en forraje de maíz el incremento fue de 327%. (Cuadro 2)

En el análisis económico que se realizó para obtener los ingresos netos por unidad de superficie, una vez descontando el costo de cultivo, el tratamiento de temporal auxiliado supero en forma significativa al tratamiento de temporal; que en el caso de frijol y girasol tiene valores negativos. (Cuadro 3)

Cuadro 2. Rendimientos promedio de cultivos y nivel de significancia en el sistema de producción. Sandovales, Aguascalientes, México. 1986.

Cultivo	Rendimiento % kg/ha		
	I) Temporal	II) Temporal auxiliado	% Incremento
Maíz grano	518	2000 *	386
Maíz forraje	721[a]	2360[a] *	327
Frijol	281	876 *	312
Girasol	91	524 *	576

* Significativo $\alpha = 0.05$

a Materia seca

Cuadro 3. Ingreso neto por cultivo en el sistema Sandovales, Aguascalientes, México. 1986.

Cultivo	Ingreso Neto $ *	
	I) Temporal	II) Temporal auxiliado
Maíz	7,138[1]	181,888[1]
Frijol	- 14,781	109,334
Girasol	- 34,246	61,922

1) Considerando grano y forraje

* Pesos mexicanos

CONCLUSIONES

En el área de temporal deficiente en Aguascalientes, México; el captar agua de lluvia es importante porque permite dar uno o dos riegos suplementarios, incrementando la producción de grano y forraje en maíz, frijol y girasol.

El tratamiento de temporal auxiliado genera ingresos netos superiores, que desde el punto de vista económico adquieren relevancia para la agricultura de temporal de subsistencia.

Los datos experimentales presentados en este trabajo son de un solo año; sin embargo, nos dan idea de la importancia productiva y económica de este tipo de sistemas de producción, en temporal semiárido.

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RESUMEN ESPANOL DE PONENCIAS INGLES

HALOPHYTIC FOOD CROPS FOR ARID LANDS

CULTIVO DE HALOFITAS ALIMENTICIAS DE LAS ZONAS ARIDAS

James W. O'Leary

La domesticación de las halófitas podría -- constituir una "nueva" fuente extensiva de agua disponible para la producción de cosechas alimenticias. La alta productividad de valiosos productos agrícolas de las halófitas bajo irrigación - con agua altamente salina, ya ha sido demostrada, pero los aspectos del manejo suelo/agua de la - - agricultura con agua salada todavía no han sido - adecuadamente dirigidos y pueden ser la mayor limitación para extender su adopción.

AN ECOLOGICAL APPROACH TO CLASSIFYNG SEMIARID PLANT COMMUNITIES

UN ENFOQUE ECOLOGICO PARA CLASIFICAR LAS COMUNIDADES DE PLANTAS SEMIARIDAS.

Richard E. Francis y Earl F. Aldon

Las variables de la vegetación en cobertura foliar, densidad, frecuencia y subsecuentes valores de importancia, fueron usadas en un análisis de conglomerados jerárquicos para cuantificar y- clasificar las comunidades de plantas. Como un - ejemplo de este enfoque, las comunidades de plantas fueron clasificadas en una cuenca semiárida - en el noroeste de Nuevo México. Este enfoque proporciona una base ecológica cuantitativa para interpretar y monitorear la dinámica del ecosistema (tendencia).

A HIERARCHICAL CLASSIFICATION OF LANDFORMS: SOME IMPLICATIONS FOR UNDERSTANDING LOCAL AND REGIONAL VEGETATION DYNAMICS

UNA CLASIFICACION JERARQUICA DE LAS FORMAS DE TERRENO.
ALGUNAS IMPLICACIONES PARA COMPRENDER LA DINAMICA DE LA VEGETACION LOCAL Y REGIONAL.

Steven M. Wondzell, Gary L. Cunningham y Dominique Bachelet

Los análisis de suelos y vegetación en el sitio experimental ecológico de largo plazo "Jornada", han demostrado estrechas relaciones entre - las comunidades vegetales y las formas del terreno. Las observaciones indican que patrones similares de vegetación existen a lo largo de la división de las partes altas de México, de las - - areas de cuencas y de pastizales. Un modelo generalizado a nivel de paisaje se presentó para intentar explicar las tendencias de desertificación, produciendo un mosaico vegetacional de arbustos - y pastizales que ahora se encuentran al sur de -- Nuevo México.

A FOREST HABITAT TYPE CLASSIFICATION OF SOUTHERN ARIZONA AND IT'S RELATIONSHIP TO FORESTS OF THE SIERRA MADRE OCCIDENTAL OF MEXICO

CLASIFICACION DE UN TIPO DE HABITAT FORESTAL EN EL SUR DE ARIZONA Y SU RELACION CON LOS BOSQUES DE LA SIERRA MADRE OCCIDENTAL DE MEXICO

Esteban H. Muldavin y Robert L. DeVelice

Un análisis florístico de las comunidades - forestales climax (tipos de habitat) del sur de- Arizona, revelan que de las 51 asociaciones de - plantas presentes, 22 están restringidas a E.U.A. en la región sur de el Mogollon en Arizona y tienen afinidades florísticas cercanas con los bos-- ques de La Sierra Madre Occidental de México. Estos bosques de baja elevación están caracterizados por los encinos xerófitos dominados y/o pas-- tos de la estación cálida. Un caso de estudio de un tipo de habitat en Arizona y México, indica que la complejidad de las comunidades forestales incrementan ampliamente en el norte de México, como una función de la proliferación de especies de encino y pino. Esto se observa como una ayuda al desarrollar un tipo de clasificación de habitat en México. Una vista general de la metología de tipos de habitat, se presenta junto con aplicaciones de manejo, con énfasis en la productividad de madera.

A RESEARCH STRATEGY ECOLOGICAL SURVEY: FLORISTICS AND LANDUSE IN THE TAMAULIPAN THORNSCRUB, NORTH-EASTERN MEXICO

UNA ESTRATEGIA DE INVESTIGACION PARA INVENTARIOS ECOLOGICOS: FLORISTICOS Y DE USO DE SUELO EN EL MATORRAL ESPINOSO TAMAULIPECO, NORESTE DE MEXICO

Nick Reid, Mark Stafford Smith,
Peter Beyer-Münzel y Jorge Marroquín

Se ha desarrollado una estrategia de investigación para identificar los efectos ecológicos del manejo y el medio ambiente físico en los matorrales espinosos subtropicales y semiáridos en el noreste de México. La clasificación y la ordenación de los análisis de muestras estraficadas - de vegetación, a través de un número pequeño de - subregiones climáticas, tipos de subestratos y situaciones topográficas, sugieren que estas variables fueron responsables de diferencias florísticas mayores. La distribución de la mayoría de las especies de plantas estuvo relacionada con la variación del medio ambiente físico. El ordenamiento de las muestras en cada grupo florístico mayor, reveló la evidencia de cambios de vegetación debidos al sobrepastoreo, pero no a los cortes selectivos de madera o leñas.

PLANT GENETIC RESOURCES THREATENED IN NORTH AMERICAN DESERTS: THE FLORUTIL CONSERVATION PROJECT

RECURSOS GENETICOS DE PLANTAS AMENAZADAS DE LOS DESIERTOS DE NORTEAMERICA: EL PROYECTO DE CONSERVACION FLORUTIL.

Gary P. Nabhan,
Wendy Hodgson y
Luis Hernández

Científicos de los Estados Unidos de América y México, colaboran actualmente en un banco - de datos sobre las plantas amenazadas en los estados fronterizos de ambos paises, al cual se ha denominado florutil. El análisis de la información de los archivos Data Base III, ayudarán a - determinar cuales plantas amenazadas han sido -- usadas directamente como productos alimenticios, de fibras, medicinas, ornamentales, etc; usados indirectamente como recursos genéticos para mejoramiento: como afectan estos usos su distribución y abundancia; como las prácticas de manejo afectan esto; si la no utilización sirve de incentivo para su conservación y donde estan protegidas estas plantas actualmente in situ o ex situ.
En el presente se ha enfocado la atención a especímenes raros de las familias de cactaceae y - - agavaceae localizadas en los 4 Estados norteamericanos y los seis mexicanos.

FOREST INVENTORY AND LANDSAT MSS VEGETATION MAPPING FOR ARIZONA

INVENTARIO FORESTAL Y MAPEO DE VEGETACION CON EL LANDSAT MSS PARA ARIZONA.

J. David Born and Clifford Pearlberg

Un inventario forestal y un proyecto de mapeo de vegetación con el examinador multiespectral Landsat (MSS), fueron combinados para generar estadísticas del recurso forestal y mapas de vegetación para Arizona. Las clases de vegetación natural son mapeadas con información sobre: propiedad, elevación y pendiente. Los estimadores estadísticos fueron: area, volumen, crecimiento - y mortalidad, para cada propiedad en el estado.

CONSERVATION AND DEVELOPMENT OF FOOD AND MEDICINAL PLANTS IN THE SIERRA TARAHUMARA, CHIHUAHUA, MEXICO

CONSERVACION Y DESARROLLO DE PLANTAS ALIMENTICIAS Y MEDICINALES EN LA SIERRA TARAHUMARA, CHIHUAHUA, MEXICO

Robert Bye, Noé Meraz Cruz y
Carmen Cecilia Hernández Zacarías

Se presentan objetivos y resultados preliminares para un proyecto en la Sierra Tarahumara - (norte de la Sierra Madre Occidental), de Chihuahua, México.

El "Quelite" Thelypodiopsis byei (BRASSICACEAE), verdura comestible y endémica de las barrancas de la selva subtropical decidua y la raíz medicinal "chuchupate" Ligusticum porteri (APIACEAE), y el "matarique" Psacalium decompositum (ASTERACEAE), son de importancia local y nacional. Para prevenir la extinsión de estas económicamente importantes hierbas, asi como para incrementar su uso en la dieta actual, salud y comercio de los indios Tarahumaras.

INCREASING PRODUCTIVITY IN THE MATORRAL OF NORTH-EASTERN MEXICO: DOMESTICATION OF TEN NATIVE MULTIPURPOSE TREE SPECIES

INCREMENTO EN LA PRODUCTIVIDAD DEL MATORRAL DEL NOROESTE DE MEXICO: DOMESTICACION DE DIEZ ESPECIES ARBOREAS DE USO MULTIPLE

R. Foroughbakhch, R. Peñaloza y
H. Stienen

Se plantaron diez especies nativas de árboles de uso múltiple del matorral de las planicies costeras del noroeste de México, de acuerdo con cuatro bloques aleatorios en monocultivo. Se evaluaron las mediciones de varios parámetros de crecimiento durante tres años. Leucaena leucocephala tuvo el mejor comportamiento mientras que dos Prosopis spp y Helietta parvifolia, la única no leguminosa, no se establecieron bien, debido a problemas bióticos, los cuales surgieron bajo las condiciones de la plantación. Tres Acacia spp y dos Pithecellobium spp (ébano y tenaza) presentaron altas producciones lo cual es de gran interés dado su potencial de uso múltiple, por lo que son las mejores de las diez especies. Estas podrían ser de gran importancia en la rehabilitación de partes gravemente degradadas de matorral, antes de que estas áreas se deterioren a condiciones de desertificación irreversible.

REVISED UNIVERSAL SOIL LOSS EQUATION FOR WESTERN RANGELANDS

REVISION DE LA ECUACION UNIVERSAL DE PERDIDA DE SUELO PARA LOS AGOSTADEROS DEL OESTE

M.A. Weltz, K.G. Renard y
J.R. Simanton

La ecuación universal de pérdida de suelo (cusle) fue revisada para adecuarla a las condiciones de campo encontradas en el oeste de los Estados Unidos. La revisión usa un subfactor de aproximación para evaluar el factor "C" y algoritmos adicionales para describir los factores "LS" y "P".

Se presenta un procedimiento para estimar la biomasa superficial, la biomasa de las raíces en los 100 mm superiores del perfil del suelo de varios tipos de vegetación de agostaderos. Las estimaciones de pérdida de suelo en los agostadero se hicieron con un amplio rango de valores de factor supuestos, usando la USLE antigua y la revisada. También cada ecuación se usó para estimar la pérdida de suelo y los resultados son comparados con medidas reales de pérdida de suelo hechos en parcelas con lluvia simulada.

NITROGEN ENRICHMENT EFFECTS ON VEGETATION OF A NORTHERN CHIHUAHUAN DESERT LANDSCAPE

EFECTOS DEL ENRIQUECIMIENTO DE NITROGENO EN LA VEGETACION DE UNA ZONA DEL DESIERTO CHIHUAHUENSE.

Joe M. Cornelius y
Gary L. Cunningham

En el sitio NSF/LTER JORNADA se llevó a cabo un experimento a gran escala, examinando los efectos del enriquecimiento de un recurso limitante (nitrógeno) a través de un área desértica. Los resultados mostraron un aumento en la cubierta de plantas efímeras y un decremento en la diversidad de especies, en respuesta al incremento del nitrógeno, probablemente debido a cambios en los niveles de disponibilidad de recursos limitantes y disminución de la heterogeneidad en la distribución espacial del nitrógeno del suelo.

OVERPOPULATION, DESERTIFICATION, FAMINE

SOBREPOBLACION, DESERTIFICACION, HAMBRE

M. Anaya Garduño

La desertificación incluye procesos naturales o inducidos. Las naciones pobres sufren los problemas mas grandes de erosión. Es crucial planear apropiadamente el manejo de los recursos naturales a través de tecnología adecuada en términos de corto y mediano plazos. La participación de la comunidad es de gran importancia debido a que la lucha contra la desertificación involucra el mejoramiento de las condiciones de vida en las áreas afectadas por miseria, desempleo y subdesarrollo.

A STRATEGY FOR REVERSING DESERTIFICATION

UNA ESTRATEGIA PARA REVERTIR LA DESERTIFICACION

Champe Green

La solución al enigma de la desertificación ha eludido a la humanidad al menos por siete mil años, es decir desde los albores de la agricultura. Sin embargo, el reciente progreso de cuatro casos ha traido nueva luz sobre las maneras de aminorar o revertir la desertificación. Un modelo de planeación de manejo holístico ha evolucionado hasta ofrecer tanto a científicos como a nativos de las tribus, una herramienta para verificar la desertificación mientras se mejora la calidad de la vida humana.

REVERSAL OF DESERTIFICATION ON THE LOW-SHRUB COLD DESERT

COMBATE DE LA DESERTIFICACION EN LOS DESIERTOS FRIOS DE ARBUSTOS BAJOS

Warren P. Clary y
Ralph C. Holmgren

Los desiertos fríos de arbustos bajos, se han usado como agostaderos de invierno para el ganado, desde finales del siglo XIX. Las antiguas prácticas inapropiadas de pastoreo dieron como resultado un severo deterioro. Datos y observaciones en los años setentas y ochentas, sugieren que con las prácticas mejoradas de pastoreo, está ocurriendo una reducción de la desertificación.

HOW DESERTIFICATION AFFECTS NITROGEN LIMITATION OF PRIMARY PRODUCTION ON CHIHUAHUAN DESERT WATERSHEDS

COMO LA DESERTIFICACION AFECTA LA LIMITACION DE NITROGENO EN LA PRODUCCION PRIMARIA DE LAS CUENCAS DESERTICAS CHIHUAHUENSES

Walter G. Whitford,
James F. Reynolds y
Gary L. Cunningham

Se hace hipotético que el cambio de pastos amacollados perenes a ecosistemas de arbustos dominantes en el desierto Chihuahuense, han resultado en un cambio de ecosistemas limitados predominantes de agua a ecosistemas limitados de nitrógeno-agua. En las areas de arbustos, el nitrógeno y el agua estan concentrados en areas de terreno bajo arbustos individuales. Estas areas de terreno separadas, afectan el enlace temporal entre las fuentes de agua y la disponibilidad de nitrógeno. Cambios de pastizales a areas de arbustos, resultan con incrementos de variabilidad temporal y espacial de estos recursos escenciales para la producción de planta. Los modelos para predecir la productividad primaria en areas desérticas deben incluir enlaces entre los modelos mecanísticos de nitrógeno y los modelos de transporte y acumulación en escala espacial amplia de materia orgánica.

A REGIONAL CENTER FOR NEW CROPS AND AGRISYSTEMS FOR DRYLANDS IN MEXICO

UN CENTRO REGIONAL PARA NUEVOS CULTIVOS Y AGROSISTEMAS EN AREAS SECAS DE MEXICO

Kennith E. Foster y
Robert G. Varady

Virtualmente la mitad de México es árido o semiárido y la mayor parte no es apropiada para la agricultura de riego convencional. La Nación como sea, ha resuelto incrementar la superficie productiva en estas regiones. El éxito requerirá de la cuidadosa selección de cultivos y del desarrollo de sistemas de cultivo inovadores y adaptativos. El establecimiento de un Centro para nuevos cultivos y agrosistemas es una estrategia para demostrar la factibilidad de cultivos y técnicas seleccionadas.

CONVERTING FORAGE TO FOOD WITH CATTLE ON THE SANTA RITA EXPERIMENTAL RANGE

TRANSFORMACION DEL FORRAJE EN ALIMENTOS A TRAVES DEL PASTOREO EN LA ESTACION EXPERIMENTAL DE SANTA RITA.

S. Clark Martín

Los pastos perennes son las plantas forrajeras más productivas en Santa Rita, aunque arbustos como el mezquite (Prosopis juliflora var. velutina) y otras plantas anuales, a veces incrementan la calidad forrajera. Las existencias razonables y una rotación adecuada y oportuna son esenciales para mantener una producción elevada.

STRATEGIES FOR ENHANCED PRODUCTION OF BEEF AND JOJOBA ON NORTHERN BAJA CALIFORNIA RANGELANDS

ESTRATEGIAS PARA EL AUMENTO DE PRODUCCION DE CARNE Y JOJOBA EN LOS AGOSTADEROS DE BAJA CALIFORNIA NORTE

Alvin L. Medina y
Jorge Sepulveda Betancourt

Un avaluación económica de masas de jojoba, pastoreo vs no pastorea, reveló que pastoreo por ganado significamente disminuió la producción de semilla de jojoba. La producción de semilla en áreas sin pastoreo fue 1.2 y 2.7 veces más que áreas con pastoreo. Tratamientos, como removimiento de vegetación y microcuencas aumentaron la producción por 2-2.7 veces más que áreas con pastoreo y sin tratamiento. La exclusión total de ganado, además, resultó en una perdida de forraje y producción de carne. Estrategias para utilizar masas de jojoba por ganado, en base de dos atributosde la planta (altura y dosel), se proponen para el aumento de carne, jojoba, y otros recursos del campo.

OPPORTUNITIES FOR MULTIPLE USE VALUES IN THE ENCINAL OAK WOODLANDS OF NORTH AMERICA

OPORTUNIDADES PARA VALORAR EL USO MULTIPLE EN LOS ENCINARES DE NORTEAMERICA.

Peter F. Ffolliott and
D. Phillip Guertin

Se describen los valores del uso múltiple para las areas de encinares del suroeste de los Estados Unidos de América y Norte de México. Se reportan las producciones de madera y forraje, así como información sobre el valor de la fauna silvestre y de otras alternativas de uso multiple. Tambien se resumen aspectos relativos a las necesidades de investigación para un mayor conocimiento y manejo adecuados mediante la valoración del uso múltiple.

AN ANALYSIS OF RUNOFF AND SEDIMENT YIELD FROM NATURAL RAINFALL PLOTS IN THE CHIHUAHUAN DESERT

UN ANALISIS DEL ESCURRIMIENTO Y LA GENERACION DE SEDIMENTO EN PARCELAS CON LLUVIA NATURAL EN EL DESIERTO CHIHUAHUENSE.

Susan B. Bolin y Tim J. Ward

Se analizaron, el escurrimiento y la sedimentación en pequeñas parcelas con lluvia natural en el desierto chihuahuense. No se encontraron diferencias significativas entre las parcelas con arbustos y las parcelas sin arbustos. Esto crea la hipótesis que cualquier diferencia causada por la cubierta no fue detectada debido a los bajos niveles de energía de las lluvias naturales. Estos hallazgos implican que las decisiones de manejo para la manipulación de la vegetación deberían incluir información de eventos de lluvias con alta energía.

A BASELINE OF SOIL EROSION AND VEGETATION MONITORING IN DESERT GRASSLANDS, CHIHUAHUA, TEXAS AND NEW MEXICO:

BASES PARA LA EVALUACION DE LA EROSION DEL SUELO Y DE LA VEGETACION EN LOS PASTIZALES DESERTICOS DE CHIHUAHUA, TEXAS Y NUEVO MEXICO:

John A. Ludwig y William H. Moir

En 1981 se inició una evaluación a gran escala de los cambios en la vegetación y en el suelo de los pastizales áridos del Norte del Desierto Chihuahuense, como parte del programa contra la desertificación USDA/SEA. Se ubicaron cinco areas de estudio en la Estación Experimental Jornada, en Otero Mesa, y en las montañas Peloncito en Nuevo México; en el Parque Nacional Big Bend en Texas; y en el Rancho La Campana en Chihuahua, México. Se hicieron mapas de la vegetación mediante cuadrantes de 30 m en transectos permanentes en esas áreas de estudio Se usó un nivel de alta presición para determinar los datos de la evaluación inicial de los niveles de la superficie del suelo a lo largo de los transectos. En el futuro la actualización de los mapas y la remedición de la superficie del suelo podrán proporcionar información sobre los niveles del cambio. Esa información podrá usarse para validar modelos diseñados para predecir los niveles de erosión y de cambios de la vegetación.

DESIGN AND OPERATION OF A WATER HARVESTING AGRISYSTEM

DISEÑO Y OPERACION DE UN AGROSISTEMA DE COSECHA DE AGUA

Martín M. Karpiscak,
Kennith F. Foster y
R. Leslie Rawles

Se desarrolló un agrosistema para cosechar agua para el desarrollo de cultivos en granjas retiradas de la irrigación. La superficie del suelo fue conformada y después se distribuyó cloruro de sodio con rastrillo en la superficie y se compactaron las microcuencas. Plantas tales como eucaliptos, pinos brutia y de alepo, cipres arizónica, duraznos, manzanos, chabacanos y arbustos salados han tenido un crecimiento exitoso.

USING NATURAL DESERT ECOSYSTEMS AS MODELS FOR AGROFORESTRY: THE GRAY, SPINEY REVOLUTION

USO DE ECOSISTEMAS DESERTICOS NATURALES COMO MODELOS PARA AGROSILVICULTURA: REVOLUCION ESPINOSA GRIS

Gary Paul Nabhan

Debido a que los recursos acuíferos de la superficie y del subsuelo tendrán una gran demanda en los desiertos norteamericanos, debemos considerar con mayor posibilidad la producción de alimentos de temporal basada en multicultivos de plantas nativas e introducidas. La diversidad de formas de vida y la heterogeneidad estructural de las comunidades de plantas del desierto, pueden servir como modelos para la Agrosilvicultura.

English Abstracts of Papers in Spanish

LA IMPORTANCIA DE LAS PLANTAS SILVESTRES PARA LA PRODUCCION DE ALIMENTOS EN MEXICO.

THE IMPORTANCE OF NATIVE PLANTS TO FOOD PRODUCTION

Carlos E. González Vicente

The paper presents general information about the importance of arid zones in Mèxico, its extension, population and potential related to food production from wild plants. There are many contributions from desert wild plants to the diet of the Mexican people.

MODELO PARA PREDECIR PRODUCCION DE HOJA DE OREGANO (LIPPIA BERLANDIERI) EN POBLACIONES NATURALES EN JALISCO, MEXICO

A MODEL FOR PREDICTING LEAF PRODUCTION OF OREGANO (LIPPIA BERLANDIERI) IN WILD STANDS IN JALISCO, MEXICO

J. Rafael Cavazos Doria

Some environmental factors were evaluated - in this study which affect oregano production. The best statistical model found to predict dry-leaf weight is the average canopy as an independent variable. There was no significant correlation between environmental factors as soil characteristics and oregano leaf production.

MANEJO DE PINOS PIÑONEROS PARA LOS PIÑONES

PINYON PINE MANAGEMENT FOR PINYON NUTS

Elbert L. Little, Jr.

Some suggestions are offered for management of pinyons for the edible seeds or pinyon nuts under multiple use. Mexican species such as *Pinus maximartinezii* merit research in sample plots. It is desirable to utilize forest genetics. The harvest of seeds can be increased. More machinery is needed for shelling the seeds.

INDICE DE DIVERSIDAD DE ESPECIES PARA DETERMINAR TAMAÑO DE MUESTRA EN VEGETACION DE BAJA CALIFORNIA SUR

SPECIES DIVERSITY INDEX TO DETERMINE SAMPLE SIZE OF VEGETATION OF BAJA CALIFORNIA SUR

Ricardo Almeida Martínez,
Homero Fraga Mancillas,
Jorge Agúndez

Within six exclosures in the southern part of Baja California, a vegetation inventory was made, utilizing grids of $25m^2$ considered as the sample unit. This procedure allowed evaluations of diversity index for the species having in purpose to find a satisfactory level of information. At all cases an asending level was found, but only two showed satisfactory level of information.

INTRODUCCION AL ESTUDIO DE LAS PLANTAS ALIMENTICIAS DE BAJA CALIFORNIA SUR

INTRODUCTION TO THE STUDY OF THE BAJA CALIFORNIA SUR EDIBLE PLANTS.

Heriberto Parra H.

This study summarizes and systematizes the information on the use and utilization of the wild edible plants of Baja California Sur, Mexico according to Guaycuras and Pericues, indians of that region as well as the post-missional colonizers. 106 edible plants were listed as result of literature review and personal inquiring which belong to 57 genera of 29 families, Cactaceae and Mimosaceae the most important.

In conclusion the edible plants of Baja California Sur are considered very important new food sources for human consumption. Their adaptation and low water requirement makes them good prospects for agronomic uses that could generate new crops for arid lands.

DIAGNOSTICO DE LA PAPITA GUERA (Solanum spp) EN EL ALTIPLANO POTOSINO ZACATECANO, MEXICO

THE DISTRIBUTION OF NATIVE WHITE POTATO (Solanum spp) IN THE POTOSINAN-ZACATECAN HIGHLANDS OF - MEXICO

Soledad Hernández Jabalera

The wild white potato (Papita güera) is a native plant used as food in central Mexico. This study found it's distribution has decreased, there are different species present and there are very few attempts by people to cultivate this plant.

PRODUCCION COMERCIAL DE CACTACEAS AMENAZADAS EN ZONAS ARIDAS

COMMERCIAL PRODUCTION OF ENDANGERED CACTI IN ARID ZONES

Guadalupe Malda y Jorge Jiménez

Overcollection of some cacti species has decreaced their natural populations. In an ejidal pilot nursery, farmers were compensated for propagating and trading the natural resources. We practice vegetative and sexual reproduction techniques. A population evaluation of the species determined the harvest of seeds and cuttings.

EVALUACION DE LA VARIACION EN FORMAS DE NOPAL (Opuntia spp) TUNERO EN LA ZONA CENTRO DE MEXICO

EVALUATION OF PRICKLY PEAR (Opuntia spp) FORM AND VARIATION IN THE CENTRAL PART OF MEXICO.

Eulogio Pimienta Barrios,
Adriana Delgado Alvarado y
Ricardo Mauricio Leguizano

The evaluation of wild and cultivated prickly pear populations in the Central Zone of Mexico, revealed the existence of large variation. This variability was expressed in terms of morphology of cladodes and fruits; time of fruit ripening; fruit weight and color; proportion of fruit components (peel, pulp, and seeds) and chemical composition of fruit pulp and seeds.

MANEJO Y COMERCIALIZACION DE LA LECHUGUILLA EN ZONAS ARIDAS DE TAMAULIPAS

MANAGEMENT AND COMMERCIALIZATION OF LECHUGUILLA IN THE ARID ZONES OF TAMAULIPAS, MEXICO

Luis Hernández Sandoval
Jorge Jiménez Pérez

The lechuguilla is an overexploited resource in Tamaulipas. This study presents management guidelines for both traditional and modern technology. This information will improve both fiber quality and commercialization. The quality of the fiber as "ixtle" can be improved and this will inhance the farmer's income.

CORRECCION DE TORRENTERAS PARA LA PRODUCCION DE FORRAJES EN ZONAS ARIDAS

WATER HARVESTING FOR FORAGE PRODUCTION IN ARID LANDS

Carlos A. Berlanga Reyes

The purpose of this study was to find ways to manage the run-off water using contour lines, the establishment of desirable forage plants and erosion control. The best results were obtained clearing the land to establish Cenchrus ciliaris in the contour lines and Atriplex canescens on the rest of the areas.

Soil water conservation and land preparation are the best practices to succeed in the re-establishment of forage plants and improve carrying capacity of degraded lands.

MANEJO DE SUELOS SALINOS Y SALINO-SODICOS

SALINE AND SODIC-SALINE SOIL MANAGEMENT

Gustavo J. Lara Guajardo

There are large acreages with saline problems im Mexico. This causes problems in the vegetation management and consequently affects productivity. To improve these conditions, it is necessary to utilize physical and biological methods for the utilization and rehabilitation of these areas.

SISTEMA INTEGRAL DE PRODUCCION AGROPECUARIA EN TEMPORAL EN EL LLANO DE AGUASCALIENTES, MEXICO.

INTEGRATED SYSTEM OF SEASONAL LIVESTOCK AND AGRICULTURE PRODUCTION ON THE PLAIN OF AGUASCALIENTES, MEXICO.

S. Hernández, J. Andrade, R. Claveran, F. Gutierrez, L.M. Macias, S. Martín del Campo, R. Ocha, M. Tiscareño, A. Torres, A. Valdez y R. Zapata.

A system for seasonal livestock and agriculture was evaluated based on crops and forage production. This was done to improve the self-sufficiency of farmers in this region. After three years of evaluation the system covered the basic food needs for one family.

SISTEMAS DE PRODUCCION EN ZONAS ARIDAS (EXPERIENCIA EN LATINOAMERICA)

PRODUCTION SYSTEMS IN ARID ZONES (LATINOAMERICAN EXPERIENCE)

Lorenzo J. Maldonado Aguirre

This paper describes and names the most important agroforestry systems in Latin America. They are: Agrosilvicultural, Silvopastoral and Agrosilvipastoral.

PROPUESTA METODOLOGICA PARA DETERMINAR LA RELACION AREA-SIEMBRA-ESCURRIMIENTO EN CULTIVOS DE TEMPORAL

A METHOD TO DETERMINE THE RELATION OF WATER HARVESTING AREA TO PLANTING AREA ON SEASONAL CROPS

José Villanueva Díaz
Ignacio Sánchez Cohen
Hugo A. Velasco Molina

A mathematical model is proposed for "in situ" water harvesting on crop production in arid and semiarid lands. The model integrates the diverse factors of climate, soil and plants. This relationship, theoretically satisfies the water requirement of the crop.

MANEJO ECOLOGICO DE UN BOSQUE DE PINOS PIÑONEROS EN TAMAULIPAS

ECOLOGICAL MANAGEMENT IN A PINYON PINE FOREST IN TAMAULIPAS

Humberto Suzán Azpiri y José Antonio Galarza.

Forest mensuration, distribution, seed germination, floristic composition and etnobotanic studies and site clasification analysis were developed in natural Pinus nelsonii populations. The results show density and spatial arrangements dependent on slope orientation; a very strong correlation among alometric variables; a multiple use of forest products, and seed overcollection in the area where found.

PASTOREO SIMULADO EN TRES ETAPAS VEGETATIVAS DE MUHLENBERGIA PORTERI SCRIBN. EX BEAL

SIMULATED GRAZING IN THREE PHENOLOGICAL STAGES OF MUHLENBERGIA PORTERI SCRIBN. EX. BEAL

Ricardo Almeida Martínez and
Gary B. Donart

Ninteen variable measurements were made to a group of plants of Muhlenbergia porteri representing three phenological stages during the first year, and consequently during a second year, in order to determine clipping affect.

Multivariate analysis, discriminant analysis, was utilized to eliminate variables. The result was that plant height defined effectively the clipped plants when measured at the initial vegetative cycle of growth.

POTENCIAL HIDRICO DIURNO Y ANUAL DE PINUS CEMBROIDES ZUCC. Y PINUS DISCOLOR BAILEY AND HAWMKS, EN LAS SERRANIAS MERIDIONALES DE SAN LUIS POTOSI.

DAILY AND ANNUAL WATER POTENTIAL OF PINUS CEMBROIDES ZUCC. AND PINUS DISCOLOR BAILEY AND HAWMKS, IN THE SAN LUIS POTOSI SOUTHERN MOUNTAIN RANGE.

Héctor M. Benavides Meza, Edmindo García Moya.

Water potential (Ψw) of the pinyon pine species Pinus Cembroides and P. discolor were studied, one day per month for a year under field conditions. P. cembroides has lower values of Ψw than P. discolor, though these diferences were not always statistically significant. In addition, it was found a threshold values of Ψw. In P. discolor this value is between -0.9 to 1.1 MPa and for P. cembroides it is between 1.1 to - 1.3 MPa, that cajused a stomatal closure and an increment in Ψw in subsequent readings.

UN SISTEMA DE CAPTACION Y APROVECHAMIENTO DE AGUA DE LLUVIA, COMO ALTERNATIVA PARA LA PRODUCCION - AGRICOLA EN TEMPORAL DEFICIENTE.

HARVESTING AND MANAGEMENT OF RAINFALL AS AN ALTERNATIVE FOR AGRICULTURAL PRODUCTION WITH LIMITED RAINFALL

Ernesto Martínez Meza

This work was carried out in Aguascalientes, Mexico, in order to harvest and distribute the rainfall to irrigate cor, beans and sunflower. The yield results showed increares in grain of 386, 312 and 576% respectively; the forage produced with corn plants increased 327%.

MANEJO INTEGRADO DE LA CUENCA HIDROLOGICA "EL PLATEADO"

INTEGRATED MANAGEMENT IN THE WATERSHED "EL PLATEADO"

Ramón Claverán A.,
Carlos Sánchez B.,
Susana Paulín W. y
Abraham de Alba A.

This work was began to solve desertification problems, using watershed to study energy reserves, flux and exchange rates of energy, water and nutrients. This research integrates man and his relationship with the environment.

ENSAYO DE OCHO CLONES DE NOPAL TUNERO EN AGUASCALIENTES, MEXICO

A STUDY OF EIGHT PRICKLY PEAR CLONES IN AGUASCALIENTES, MEXICO

Francisco Gutiérrez Acosta

Eight Prickly pear clones were evaluated according to plant and fruit characteristics. No statistical difference was found among clones. The average production in the five year study was from 14.4 to 16.7 metric tons per hectare.

BALANCE HIDRICO EN MAIZ DE TEMPORAL EN AGUASCALIENTES, MEXICO

WATER BALANCE ON CORN PRODUCTION WITH LIMITED NATURAL RAINFALL

Miguel Angel Martínez Gamiño

Measurements were made on surface run-off, water erosion and its control, evapotranspiration and corn yield. A layer of 50 ton/ha of straw reduced surface run-off by 33% and 80% water erosion.

The low rainfall during the kernel formation, affected the yield by more than 100%.

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Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

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Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
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**General Technical
Report RM-151**

Meeting the Challenge of the Nineties:

Proceedings, Intermountain Forest Nursery Association

August 10-14, 1987
Oklahoma City, Oklahoma

Landis, Thomas D. 1987. Meeting the challenge of the nineties: proceedings, Intermountain Forest Nursery Association; 1987 August 10-14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 138 p.

Abstract

This proceedings is a compilation of 27 articles on various phases of forest nursery management. Specific topics include: seed treatments, soil management, cultural practices, seedling quality, and nursery pests. Results of a discussion on the nursery competition issue are also presented.

NOTE

As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential users as quickly as possible. To do this, we asked each author to assume full responsibility for submitting reviewed manuscripts in photoready format within tight deadlines. Thus the manuscripts did not receive conventional Forest Service editiorial processing, and consequently, you may find some typographical errors and slight differences in format. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations.

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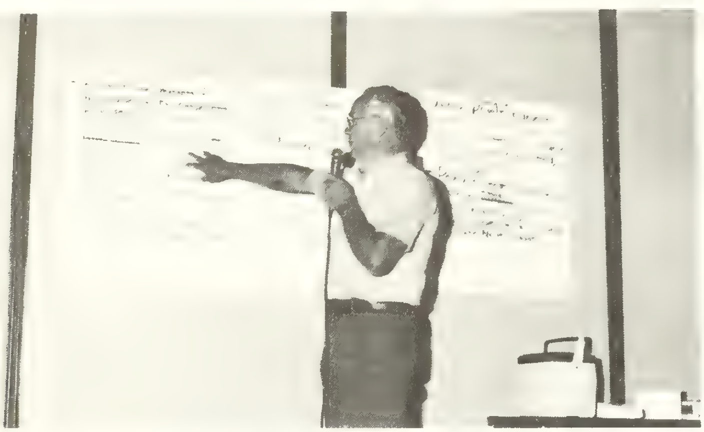

Contents

Seedlings, Service, and Insights[1]

Carl E. Whitcomb[2]

INTRODUCTION

Bed-grown tree seedlings have been produced for many years with variable performance at outplanting. Slowly, container-grown seedlings have gained in popularity in spite of their higher cost. But what about the future? Here is one practical research/practioner's outlook.

Over the years much of the variability among seedlings has been attributed to genetics. If 100 viable seeds of most species are planted in a seed bed, the resulting seedlings generally grow at different rates. Container-grown seedlings are generally somewhat less variable. This slight improvement in uniformity is mostly attributed to more precise control of cultural conditions.

In the fall of 1985 the opportunity arose to examine the roots of 720 trees, 180 each of four species: lacebark elm, *Ulmus parvifolia;* shumard oak, *Quercus shumardi;* loblolly pine, *Pinus taeda;* and Chinese pistache, *Pistacia chinensis.* They had been grown in bottomless milk carton containers for approximately three months, then transplanted into two-gallon poly bag containers for the remainder of the first growing season and planted into the field in October. There were approximately 500 seedlings of each species in the poly bags from which the most uniform 180 were selected to minimize genetic variability. After two growing seasons in a sandy clay loam soil of moderate fertility, some trees had grown very little, while others exceeded nine feet in height and two-inch stem diameter. Could all of this variation be due to genetics or was something else involved?

Three days were required to excavate the 720 trees with a backhoe. All of the larger trees had large root systems but was this a factor of genetics? Counts of roots 3/4-inch in diameter or larger were poorly correlated with tree size. Counts of roots at a point approximately 12 inches from the stem were also poorly correlated with tree size. However, when counts of roots approximately 1/8-inch in diameter or larger arising from the root/stem interface were taken, a striking correlation resulted (Figure 1). Only data and photo of the lacebark elm are included, since all four species responded similarly.

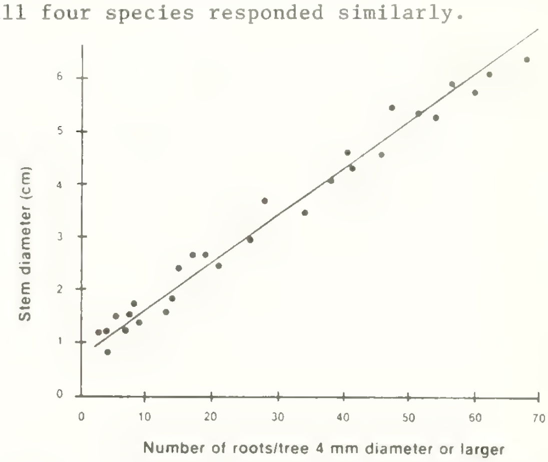

Figure 1. Relationship of number of roots arising from the root/stem interface and stem diameter of lacebark elm.

These data suggest that <u>where</u> the roots branch is very important and that this may be a major factor affecting the rate of tree growth. Thus, a genetically superior tree with a poor root system may only grow at a slow to moderate rate.

A NEW CONTAINER

To utilize this information, a unique new propagation container was designed. Called the Root Maker (U.S. and other patents pending), this container is 2.6 inches square and four inches deep and air-prunes the root system both at the bottom and on the sides (Figure 2). The bottom is shaped somewhat like a pyramid so that the taproot and any secondary roots that reach the bottom will be air-pruned at one of four drain holes. Secondary roots that grow outward are guided to air-pruning openings in the sides. The four-inch depth forces secondary root branching at, or near, the base of the stem. Individual containers lock into a frame for ease of filling and handling and to insure proper spacing, yet can be easily removed for shipping or planting.

This data also suggests that bed-grown seedlings should be root-pruned early and perhaps often. A wider spacing will also be necessary to accommodate more lateral roots.

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[1]Paper presented at the 1987 meeting of the Intermountain/Great Plains Nursery Association.

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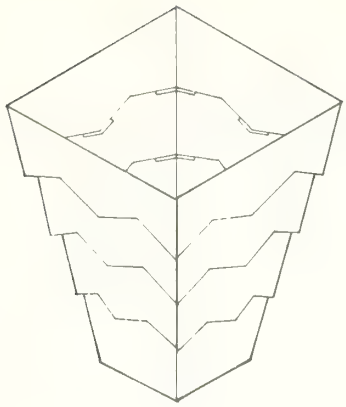

Figure 2. The Root Maker container air root-prunes tree seedlings on the sides as well as at the bottom. In addition, by controlling the depth, the root system is forced to branch at the root/stem interface to enhance tree growth.

NUTRITION

Proper nutrition can enhance plant growth and health and minimize other problems. The key is the synchronization of all of the essential elements. Studies with container-grown seedlings suggest that nitrate nitrogen, phosphorus, and the micronutrients are key factors.

Seedlings appear to have a limited capacity to utilize ammoniacal nitrogen, but do respond to nitrate. Phosphorus is very important. Potassium can vary considerably without affecting growth. The micronutrients play a key role in enhancing overall plant health and stem and root development. They can be added to the mix using research-formulated blends such as Micromax micronutrients that also provide sulfur.

The two major nutritional variables that are unique to each specific production site are calcium and magnesium. If pine bark or other wood product is used as a component of the growth medium, it should be analyzed for calcium and magnesium. However, the analysis must be done using an ammonium acetate extract to determine the levels available to the plant. Water extracts show only what will readily leach out. Strong acid extracts give inflated values due to partial or complete destruction of the particles.

Water quality is a variable that must be considered in the production of both container and field production of seedlings. The levels of calcium and magnesium in the irrigation water play a key role in plant nutrition. In some cases, the irrigation water provides all of the calcium and magnesium needed. Other water provides only calcium, thus requiring a separate magnesium source. In the future, a water analysis plus growth medium analysis will be used to determine the levels of calcium and magnesium needed for optimum plant growth.

A related point is that the pH of the water gives little information regarding water quality. The pH gives only a measure of the acidity or alkalinity of the water, nothing more. A water may have a pH of 6 and contain considerable calcium or a pH of 9 and contain very little. A complete water analysis is the only way to know. Water with a high pH generally contains considerable bicarbonate which, if above about 200 ppm, must be considered in the nutritional program.

Bed-produced seedlings are affected by irrigation water quality as well. Due to the strong buffer of most soils, a longer time is generally required before the effects are noticed. Most soils labs suggest that a soil pH of 6 to 7 is ideal. This may be true for fast-growing annual crops such as corn, wheat, and soybeans, but it is not correct for trees. More precise management of this area as it affects nutrition will be required in the future.

Improved root systems in combinations with improvements in the entire water quality/nutrition complex and established good cultural practices will dramatically improve tree health, transplant success and subsequent growth. More precise production techniques will require more accurate monitoring by nursery managers. However, the payoff will be a superior product that requires fewer pesticides and is more uniform. The increased uniformity will allow further mechanization and labor savings. It all starts with the root system but the roots must be supplied with a precise nutritional program to maximize growth.

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Communications as a Design Consideration in Developing a Computerized Nursery Management Environment[1]

John R. South[2]

Abstract: The transition from a manual to a computerized is successful only if the designers consider three levels of communications in the social and technical environments. In order of importance, these levels include communications among the staff members, communications between the staff and the computer, and communications between computers.

INTRODUCTION

The purpose of this paper is to examine how three levels of communications have played an important part in the development of the nursery management tool for Oklahoma. The three levels are:

- communications between members of staff,

- communications between the staff and the computer,

- communications between the various computers in the operation.

Consideration of the levels of communication has developed from the observation that the office environment is often viewed by management as being split between social and technical considerations. The author contends that, if the manager of a nursery wants to successfully convert from a manual to an automated operation, all three levels of communication must be considered.

COMMUNICATIONS BETWEEN STAFF MEMBERS

The 'traditional' manner of software development has been for the software designers to meet with the managers and supervisors of a particular operation and decide among themselves what software is needed to automate an office. The staff workers are not brought into the picture until after the development process has been completed. Their first view of the system is when hardware and software are installed in the office. The group at the Forest Regeneration Center in Norman, Oklahoma have taken a quite different approach to the development of their system. From the first moment of development to the present time, the staff has been deeply involved in the definition of system specifications, design of the work flow in the system, and preliminary testing.

The most important role that the staff has played has been that of an information filter. The first meeting with the Oklahoma staff revealed the vast amount of paper work that an integrated nursery system would replace. In an ideal system, one of the goals of the development team is to filter the large amount of information for superfluous and redundant data (fig. 1). The members of the Oklahoma nursery have played that role of information filter.

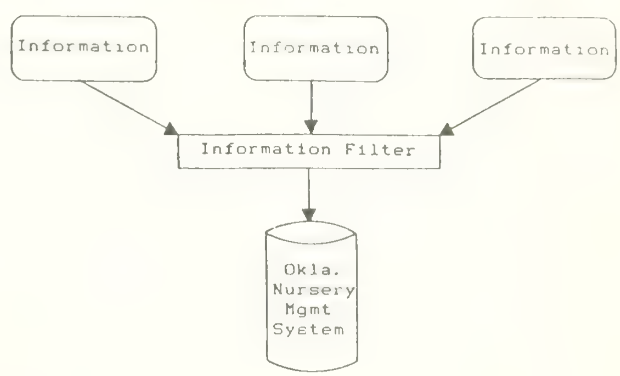

Figure 1 -- The Nursery staff acts as the filter which determines what information will be included in the automated system.

In addition to aiding in the design of the system, previewing the information proposed for inclusion in the automated operation has allowed the staff to review the data that they have been

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[1] Paper presented at the 1987 Intermountain Forest Nursery Management Association Meeting. Oklahoma City, August 10-13, 1987.

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collecting in the past. This whole process of bringing the staff into the design process has had ramifications which should last long after the automation process is complete.

Promotes a Spirit of Ownership

Bringing the staff into the development process promotes a spirit of ownership in the final product. This is important during the conversion process.

In a typical conversion process, the manual system runs parallel with the automated system. This means that the nursery staff will have to maintain both systems together for some specified length of time. The period is trying at best, but the path is much smoother when the staff feels that they have had a significant impact on the development of the product.

Provides a Creative Outlet

In the same light, including the staff in the development process allows these individuals to exercise their creative talents. It must be remembered that these are the individuals who have been performing the day-to-day tasks. Many have 'ideas' as to how the data should be collected, displayed, and reported. Involvement in system development provides a job enrichment unlike any normally available to the staff.

Lowers Resistance to Change

For long-term employees it may be difficult to accept a new way of collecting and reporting data, if an automated system is simply installed without their input. In some cases, change is a process that some staff members cannot accept; however, involvement in this type of a project at least gives the manager or supervisor an opportunity to whittle away at the resistance. Input from these long-term employees is important to the project. There may be a reason why the manual process should not be automated and this reason needs to be heard.

Reduces Training Time

A great deal of resources in the form of time and personnel may be needed to train individuals in the operation of the automated system. If these same individuals are part of the design process, they receive their training in an evolutionary manner as the project progresses. When they finish testing the final process, management will find that very little additional training will be necessary.

It is often seen that employees don't fear the changing process as much they fear the new technology. They are literally uncomfortable when they sit in front of a computer for the first time. Given incremental doses of involvement with the computer helps to lessen the apprehension these individuals feel.

COMMUNICATION BETWEEN STAFF AND COMPUTER

The Integrated Environment

The Oklahoma Nursery Management System has been designed as an integrated environment. Though it does not encompass every function encountered in the management of a nursery operation, its operation does include most of the major data-generating activities (fig. 2).

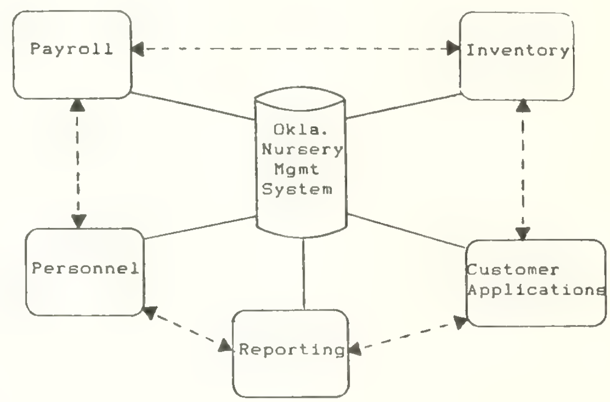

Figure 2 -- The automated environment showing the communication between the various submodules and the main environment.

As Figure 2 implies, the integrated environment was designed not only to bring all of the data activities under 'one program', but more importantly this type of configuration allows each submodule to 'talk' to those submodules which store data needed to complete a calculation. This environment is not one program but rather a number of programs linked together through a number of programming techniques. To the user, the nursery staff member, the movement from one submodule to the next is virtually transparent.

Figure 3 illustrates the concept of one submodule talking to another. In this case, the Payroll module (which, as one of its functions, collects information on cultural practices by hours for each particular species) needs the names of the species which the nursery is currently growing. So it 'asks' the Inventory module which species are currently being grown. On the other hand the Inventory module needs to calculate the cost of growing a particular species of seedling, so it 'asks' the Payroll module how many hours and in what cultural

practices time was spent on a particular species. Again, this transfer of information is totally transparent to the user, but is maintained by separate programs in the system.

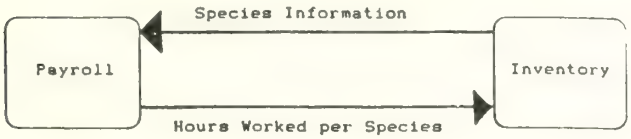

Figure 3 -- Transfer of information between two modules in the integrated environment.

A Dynamic Dialogue

Communications between the human staff member and the computer is a dynamic process. Interaction between the two entities changes from one day to the next. The problem that faces the system designer is that, once the program is installed, the program is, in a sense, in a static state. The process of moving from one part of the program to another does not change simply because it's Monday instead of Thursday. But the data and the database are dynamic. They are in a constant state of change.

Menus are the standard means of moving from one point in a program to the next (fig. 4). From the designers standpoint, menus are simple to program and they present no particular difficulty in error-checking. From the user's standpoint, menus are simple to use, self-documenting (to a point), and, in most cases, quite boring after the first few times though a program.

It seems to be a step backwards to involve your staff in the development of a computer system (where you are trying to unleash their creative talents), and then to saddle them with a system driven by one of the least creative selection mechanisms. The Oklahoma system only uses menus to move from one major program segment to the next.

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                                        8/11/87
OKLAHOMA FORESTRY DIVISION
Nursery Management System

- Inventory Main Menu -

1) Chemical Inventory
2) Seedling Inventory
3) Seed Inventory
4) Return to Main Menu
5) Quit

Select Option ==>
```

Figure 4 -- Menus are used only for movement from one major program module to another.

Data selection and data manipulation use one of two mechanisms. In a database environment, data records are selected by keys embedded in the data. In some cases a key may be an employee's name or social security number. In another case, a key may be a particular species or species code. In many cases, the key is a logical representation of the character string which actually retrieves the data. So the program must prompt the human for the information it needs to build the physical key. Figures 5 and 6 show two methods that the Oklahoma system uses to prompt the staff member for the necessary information to build a key.

In the first case (fig. 5), the staff member is using the Payroll submodule and is about to add hours (specified by cultural practice) to an employee's record. The individual entering the data is using the employee's social security number to pull up the employee's work history. The social security number may have been the only means the staff member had of identifying the employee, or the staff member may have felt that using the social security number was a faster means of getting to a particular employee's record. The point should be made that using either the name or the social security number of the employee would have led to the same record. In this case, name and social security number are alternative keys for a particular employee's record.

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                                        8/11/87
OKLAHOMA FORESTRY DIVISION
Add Hours By Category

- Enter Name Or SSN -

1) Last Name :
2) First Name:

3) SSN: 111-11-1111

- Enter The Beginning Date For Period Worked -

4) Begin Date: 08/11/87

PRESS "ESC" TO GO TO MAIN MENU
```

Figure 5 -- Data selection through alternative keys. The computer prompts the user for the information needed to locate an employee's record.

Though figure 5 appears somewhat like the menus that were slandered above for their inherent lack of creativity, the difference between the two is that in using a key screen, like that in figure 5, the staff member needs to make decisions. The first decision is what key to use. If an employee is not located using that key, the user needs to decide what alternative key to use to perform the search.

Figure 6 illustrates another mechanism which the Oklahoma system uses for gathering

information it needs for generating a key. The user is in the Inventory module and wants to add Ponderosa Pine to the species inventory. Rather than flipping to a separate screen to ask for the species name or species code, a window automatically pops up on the screen indicating to the user that the computer needs some information before it can continue its processing. The message in the bottom of the pop-up window indicates that the user used the species name as a key to the species' records. Since no species record existed for Ponderosa Pine, the computer indicates this fact and asks the user for the species code in order to complete the initial construction of the species record.

8/11/87

OKLAHOMA FORESTRY DIVISION
Species Addition Option

Enter Active Species

1) Species Name: Ponderosa Pine

2) Species Code: 11········

New species - please enter Species Code

PRESS "ESC" TO GO TO MAIN MENU

Figure 6 -- A pop-up window which prompts the user for information needed to construct the key for new species record.

The final method the Oklahoma Nursery Management system uses for obtaining a key to a specific record is shown in figure 7. Again, the pop-up window mechanism is used. In addition to alerting the user to the fact that the computer needs some piece of information, the pop-up windows eliminate a number of screens and, in some cases, a number of menus.

8/11/87

OKLAHOMA FORESTRY DIVISION
Species Update Option

Select Active Species

	Species Name	Species Code
1	Arborvitae	01
2	Austrian Pine	10
3	Autumn Olive	25
4	Bald Cypress	15
5	Black Locust	02
6	Black Walnut	08
7	Catalpa	03
8	Euonymus	27
9	Green Ash	14
10	Hackberry	18

PRESS "ESC" TO GO TO MAIN MENU

Figure 7 -- A pop-up window which allows the user to select a given species from the list of active species.

The difference in the case of figure 7 is that the choices presented to the user are fed to the pop-up window straight from the species database. The user selects the species to update by moving a cursor to the left of the number corresponding to the species of interest. By pressing the enter key, the selected species is brought into active memory and is available to the user for update.

Data Entry - A Model of Simplicity

Next to manipulating the data (producing statistics and reports), the most important function of any data processing system is incorporating data into the database, i.e. data entry. Many designers disagree on the level of sophistication of a data entry screen; but, there is no disagreement on the fact that data validation is a primary concern of the system designer. The integrity of the database is protected only to the extent that the designers provide for error checking when designing the screens. There are two basic data entry screens being used by the Oklahoma Nursery Management System. A conventional screen (fig. 8) is used for gathering most of the raw data for the database records.

8/11/87

OKLAHOMA FORESTRY DIVISION
Personnel Update Option

1) Last Name : South
2) First Name: John R.

3) Address: 6909 Custer Road, #708
4) City : Plano 5) State: TX 6) Zip: 75023

7) Phone Number: (214)964-2670 8) Soc. Sec. Nbr: 111-11-1111
9) Position: Area Forester 10) Employee Type: PERM

11) Area: C&W 12) Job Code: U102
13) Grade Step: 062-7 14) Hourly Rate: $ 15.97
15) Start Date: 08/11/87

Next Action?

PgUp-Next Rec PgDn-Prev Rec F2-Change F3-Cont ESC-Quit

Figure 8 -- A data entry used to enter personnel information. Each field is validated for type of data, length of the data field, and the range of the data.

Not all the information shown in figure 8 typed in by the user. The Oklahoma system is designed to put information on the screen for the user once it has enough data to perform this operation. For instance, in figure 8 the user would type in the employee type (PERM), area (C&W), and the job code (U102). The system determines that this data corresponds to an Area Forester of Grade 62. The user then entered the step (7) and the computer responded with the hourly rate ($15.97).

Figure 8 also illustrates one of the primary design features of the Oklahoma Nursery

Management System. At the bottom of the window is a key selection menu. If the user were to press the PgUp key, the system would bring the next personnel record up on the screen. Pressing PgDn would bring up the previous record. This one key operation is designed throughout the system and allows the user to move through the database and to select particular operations without having to go another menu or another screen.

In some cases, a large amount of numeric data needs to entered into the database. The Oklahoma system handles this by providing a matrix-like screen system (fig. 9). The upper part of the screen indicates the data record the user is working with; the bottom part of the screen is used for the data entry. Since not every field will be used for storing data, the user can move the cursor to the proper fields (not unlike a popular spreadsheet package).

```
------------------ OKLAHOMA FORESTRY DIVISION -------- 8/11/87 ----
                        Add Hours By Category
  Name:     South, John R.                    SSN:       111-11-1111
  Address: 6909 Custer Road, #708             Job Code: U102
            Plano, TX  75023                  Area:      C&W
  Postion: Area Forester                      Type:      PERM

      Enter Time Spent On The Following Categories For: 08/11/87

 1) Chemicals  > .....  10) Seed Inven.>      19) Count/Tie   >
 2) Hand Chem. >        11) Equipment  >      20) Topcut      >
 3) Weeding    >        12) Grounds    >      21) Seed Harv.  >
 4) Fertilizer >        13) Seed. Rec. >      22) Seed Proc.  >
 5) Soil Amend.>        14) Training   >      23) Planting    >
 6) Irrigation >        15) Admin.     >      24) Cult. Pact.>
 7) Site Prep. >        16) Shipping   >      25) Misc. 1     >
 8) Cover Crop >        17) Ship.Admn. >      26) Misc. 2     >
 9) Research   >        18) Mech. Harv.>      27) Misc. 3     >

 Day's Comments:
                 F2-Enter Comments     F3-End       Total Hours:

------------------ PRESS "ESC" TO GO TO MAIN MENU ------------------
```

Figure 9 -- Numeric data is entered into the database through a matrix-like screen.

In the case of figure 9, the user is entering the hours that a particular employee has spent working on the listed cultural practices. Since the hours spent on some cultural practices (for instance, weeding) need to broken down to the species which were worked, the Oklahoma Nursery Management System alerts the user to this fact by generating a pop-up window which allows the user to enter the appropriate data (fig. 10).

COMMUNICATIONS BETWEEN COMPUTERS

Communications between computers is an area which is beginning to receive a great deal of coverage in the computer press. This media coverage is doing more for the sales of expensive communications hardware and software than it is for generating legitimate development ideas in operations converting from manual to automated processes. There is no doubt that many operations will eventually evolve into systems which can effectively take advantage of concepts such as local area networking, distributed

```
---------------- OKLAHOMA FORESTRY DIVISION ---------- 8/11/87 ---
                      Add Hours By Category
   Name:    South, John R.                    SSN:      111-11-1111
   Address: 6909 Custer Road, #708            Job Code: U102
 -------------------Hours By Species--------------------  C&W
 Please Breakdown  2.00 Hours Over Species Worked On      PERM

 Arborvitae  >            Aust. Pine  >                : 08/11/87
 Cypress     >            Aust. Pine C>
 Black Locust>            Pond. Pine  >                nt/Tie   >
 Black Walnut>            Scotch Pine >                cut      >
 Euonymus    >            Shtleaf Pine>                d Harv.  >
 Green Ash   >            Virg. Pine  >                d Proc.  >
 Hackberry   >            Imp.Lob.Pine> 1.00           nting    >
 Lacebark Elm>            Cottonwood  >                t. Pact.>
 Mulberry    >            Baldcypress >                c. 1     >
 Osage Orange>            Bur Oak     >                c. 2     >
 Pecan       >  1.00      Catalpa     >                c. 3     >
 Red Ceder   >  .....     M. Rose     >
 Russ. Olive >            Redbud      >
 Autumn Olive>            Sand Plum   >                  Total Hours:
                                      Total Hours:          6.00
                                          2.00
```

Figure 10 -- A pop-up window which prompts the user for the hours by species for a particular cultural practice.

processing, and mainframe links. From what the author has seen over the past few years, some system designers get caught up in the technology and overlook the true purpose of the system. In fact, in some cases, they go so far as to purchase the hardware and then try to make the system fit the hardware.

WRONG!

The conceptual design of data acquisition and database manipulation needs to be considered first. Granted, the specifics of a particular system may necessitate a hardware intensive design, but that decision should not be made until the database design is well thought out.

In the case of Oklahoma, the nursery system is designed to be a stand-alone system. But it is also designed in such a way that, should the Forestry Division decide to expand into a different configuration, the software can be modified relatively easily to meet the changing environment.

The current system is designed to use rudimentary data communications techniques as illustrated in figure 11. The communication techniques are rudimentary in that the data files are transmitted from one node to the next manually. For instance, the Area Forester can transmit a set of data files to his Supervisor in the capital. In another case, the author's firm can transmit the latest version of a particular report schema to both the capital's computer and to the computer at the Forest Regeneration Center. The point to be made is that this is all the high tech communications the operation needs at this point in time. Some day the nursery in Norman may operate as a node in a distributed processing environment with the capital, but that day is still a ways off. The managers in that operation have made the decision to concentrate on their software environment and to develop the overall system (hardware) as an incremental process.

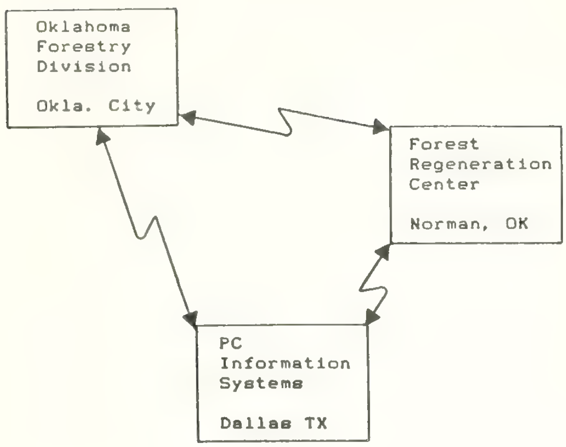

Figure 11 -- Communications between the computers involved in the Oklahoma Nursery Management System.

FINAL COMMENTS

Of the three levels of communications which the system designers need to consider when converting a manual operation to a computerized environment, the most important area of communications (from the standpoint of the nursery) is the communication among the members of the staff. This level of communications has the most far-reaching impact and will have the greatest long-range effect on the individuals in the operation.

It is inherent that the system designers stress simplicity when they develop a particular automated environment. This will lead to less resources being devoted to training and will alleviate the frustrations that the non-professional computer user feels when working with a system that is not self-documenting.

Finally, it is important that the system designers understand how hardware, software, and the evolutionary stage of the development process all relate to each other. Though it would be nice to incorporate all the neat, sophisticated hardware available, in most cases, during the manual-to-computer conversion, these high tech gadgets are inappropriate.

Applications of Portable Data Recorders in Nursery Management and Research[1]

W. J. Rietveld and Russell A. Ryker[2]

Abstract.--A portable data recorder is a specialized electronic device for recording and storing data in the field, then transmitting the data directly to a computer, eliminating the time and errors associated with manual data transcription. Use of a data recorder allows error and completeness checking in the field, direct data collection from instruments, and minimum turnaround time between data collection and completed data analysis. Considerations for selecting a data recorder to meet individual needs, and some drawbacks, are discussed. Specific applications in nursery management and research are presented.

INTRODUCTION

A portable data recorder (PDR) is a hand-held, battery-powered, microprocessor-controlled computer terminal (Cooney 1987). PDR's are specialized electronic devices designed to collect and store data in the field or laboratory (in place of data forms), then transmit the data directly to a computer for processing. They differ from laptop computers and hand-held calculators in that they are constructed for outdoor use and their main purpose is to store data, not process it. As microcomputer use increases in forestry, more resource professionals are turning to automated data processing to increase their productivity. Although computer hardware and software have advanced substantially in recent years, data are still collected and entered into computers by hand in many cases. These two steps done manually can be expensive, time-consuming, and full of errors. Alternatively, data can be keyed into a PDR as they are collected, automatically checked for errors and completeness, then the completed data file can be transmitted directly to a computer. Because manual data transcription is eliminated, PDR's can significantly reduce costs, number of errors, and turnaround time. PDR's are becoming the technological link between field measurements and data analysis.

Portable data recorders were first used in supermarkets to expedite inventories. In recent years they have found a new home in forest inventory because of the volume and diversity of data that are collected, the need for error checking during data collection, cost savings in data transcription, and reduced time to obtain results (Anonymous 1987, Bergstrom 1987, Bottenfield and Meldahl 1987, Fins and Rust 1987, Scott 1987). Bluhm (1986) recently reported using a PDR in nursery seedling inventory. Applications in research have increased in recent years, not only because more efficient data handling is needed, but also because some PDR's can be interfaced to digital and analog instruments to collect data directly.

All these applications have certain characteristics in common: (1) a large amount of data needs to be collected and transferred to a computer for summary, (2) the costs of manual data entry and verification need to be reduced, (3) errors must be minimized, and (4) the time between data collection and data processing should be reduced. In this paper, we will discuss some benefits and drawbacks of using PDR's, list some considerations to help you decide which one to purchase, and present some ways we use PDR's in nursery management and research.

SELECTING A PORTABLE DATA RECORDER

Approximately two dozen devices on the market could qualify as portable data collectors. Specifications for most of the dedicated PDR's are reviewed by Cooney (1985, 1987). They differ

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[1]Paper presented at the Intermountain Forest Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

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widely in size, environmental durability, keyboard configuration, operating system, memory capacity, programmability, and communications. Most are powered by rechargeable batteries, have some form of battery backup, and have some sort of low battery warning, so there is a low risk of losing data. The devices differ greatly in other specifications; users need to determine what configuration they need and select the appropriate device. For example, in forest inventory error-checking and completeness checking routines should be built into the data collection scheme so that complete and error-free data are obtained while the survey crew is on site. For those applications, a PDR that supports BASIC, a powerful and versatile programming language, is highly recommended. Many other applications are more straightforward, amounting to filling in the blanks with data, so a simple edit mode may suffice for entering data. Certain PDR's can be interfaced with digital and analog instruments -- such as calipers, balance, area meter, porometer, thermometer, and string potentiometer -- so that data can be transmitted directly to the data file with the push of a button. In some cases the PDR can be set up to take unattended readings from an instrument at set times. Note, however, that these applications require a custom program to read the device and record the data. All PDR's are equipped with a serial port for RS-232 communications via direct cabling or a modem to a host computer.

Programmability is desirable for controlling cursor movements, performing mathematical functions, displaying menus and messages, checking for errors, checking for completeness, and accepting data from interfaced instruments. Most devices provide some degree of programmability using either a proprietary language that the user must learn, or BASIC, a more universal language. Although the proprietary languages can be used to provide extensive error checking and to perform mathematical functions, there are advantages to purchasing a PDR that is programmable in BASIC because the same language can be used for programming on a microcomputer. However, a proprietary language may be more suitable for programming the PDR to accept data from connected instruments. While building in some programmed error checking routines and minor manipulations of the data may increase efficiency of data collection, don't expect the PDR to perform the data summary and analysis. For most applications, it is easier to first transmit the data to a computer, then perform the analyses using existing, more powerful application software. The examples in the applications section will illustrate this point.

We recommend the following approach to selecting a PDR: (1) list all applications where a PDR may be useful, (2) evaluate that list and retain only the applications where a PDR is truly needed to increase efficiency (i.e. large amounts of data, repetitive measurements, need to transmit data to a computer, minimization of errors, and cost savings from eliminating data transcription), (3) make a list of capabilities and features that the PDR must have to meet your needs, (4) compare your list against the tables of specifications provided by Cooney (1985, 1987), and (5) evaluate product information and any available published reports in making your decision. Several companies and agencies have conducted their own evaluations and may be willing to share their information.

You may also wish to evaluate the economics of using a PDR instead of conventional field forms and manual data entry. You can do this by following the procedure outlined by Fins and Rust (1987). Assuming that data collection takes the same amount of time by both methods, data transmission and manual entry times can be estimated closely enough to perform the comparative cost estimates without actually using a PDR.

DRAWBACKS TO USING A PORTABLE DATA COLLECTOR

Some special problems, limitations, and conflicts that may be encountered in using a PDR are: (1) "computer phobia", (2) limited view of the data file, (3) conflict with existing data collection methods, and (4) cabling and communications between connected devices.

Many people get "computer phobia" when they are asked to record numbers electronically rather than writing and storing them physically on a tangible sheet of paper. The task of training personnel to use a PDR should be taken seriously. It is a good idea to develop flow charts and provide practice data for them to learn with before important data are recorded. As a transition, it may be helpful to first write the data on data forms, then enter the data into the PDR.

One limitation of most PDR's is the restricted view of the data file, i.e. only a small portion of the file is seen (and accessible) on the display at one time. It is more difficult for the user to compare current measurements with previous measurements, which are more easily seen on data forms. This is not a problem if you take advantage of the PDR's power by writing a short program to have the PDR display the previous measurement (which must exist in the same file), or you can have it compare the new measurement with the previous measurement, beep if it is smaller, and otherwise enter the data in the file. A second problem related to the restricted view is keeping track of your location in the file. Because one row in the file is usually the data for one tree, beginning users may skip a tree and get out of sequence with the data file. There are two ways to avoid this problem. One is to print a copy of the data file with lines numbered so users can keep track of their location by line number, and the other is to program the PDR to display the descriptors (e.g. block, treatment, tree number) pertinent to each measurement being entered.

Use of a PDR may not be compatible with established plot measurement methods. For

example, some crews like to have one person record data while two people measure trees in adjacent rows. This does not work out very well using a PDR because it cannot easily switch back and forth in the data file. The same is true for measuring adjacent rows in opposite directions, unless either the plot or the data file is arranged that way. When using a PDR, it is easiest to enter data in the sequence they occur in the data file. If more than one person is taking measurements, they should leapfrog and provide the data in the file sequence.

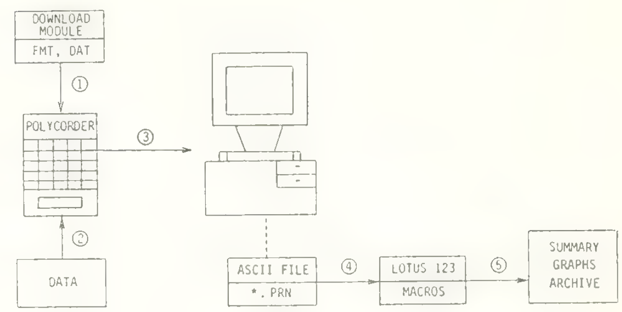
Cabling and communications between connected devices are common obstacles when any peripheral device is connected to a computer or PDR. Cabling from a PDR to a microcomputer is usually not a problem because the manufacturer often has a serial cable available. Communications between a PDR and a computer is best done with a communications program. Establishing communication is a matter of setting up matching protocol (baud rate, parity, duplex, data bits, stop bits, etc.) between the two devices. The PDR manual will usually give some helpful advice on this, but there is no one solution because computers differ widely. The same situation arises when a PDR is cabled to an instrument to collect data. In some cases, e.g. digital calipers, the device, cable, and programming may be available from the PDR manufacturer. In other cases, you purchase the peripheral device with its optional serial port, and the cabling and communications to the PDR are up to you.

SPECIFIC APPLICATIONS OF PORTABLE DATA RECORDERS

In this section we will present two applications of the Polycorder[3] (Omnidata International, Logan, UT) in nursery management and research. Published applications of other PDR's are: Hewlett-Packard model 71 (Bluhm 1986); Husky Hunter (Bergstrom 1987, Bottenfield and Meldahl 1987); Husky Special Performance (Scott 1987); Oregon Digital Serial Plus II 7100 (Anonymous 1987); and Datamyte 1003 (Nieman et al. 1984).

Nursery Application

The USDA Forest Service Reforestation Improvement Program (Rietveld et al. 1987) involves repetitive measurement of several seedling variables (seedling growth, morphology, root growth potential, cold hardiness, stress test, plant moisture stress, and field plot measurements) at 11 nurseries. The same variables are repeatedly measured using the same sampling scheme, so the basic data forms will be used over and over. To facilitate data collection, summarization, file organization, and archiving, a systematic approach was developed that utilizes the Polycorder to record the data and transmit it to a microcomputer. The following diagram shows how the data will be processed:



The Polycorder requires a format file for each data file that will be created. The format file designs the data form. The data file is the actual form, which is blank until data are entered. Format and data files may be keyed into the Polycorder, loaded from a download module (1), or downloaded from a computer. The next step is to key the data into the data file (2). This can be done in edit mode or in program mode, but the latter requires writing a short Polycode program to control cursor movements and must be matched to the number of columns receiving data. Once the data file is complete, the data are transmitted to the computer (3) using direct cabling between serial ports on each device. A communications program, Crosstalk, is used to capture the data and create an ASCII file with a .PRN extension. The ASCII data file is then imported into a preformatted Lotus 123 worksheet (4) where the data are summarized, graphs are created, and archiving is done (5) by running specialized macros (preassembled lists of commands) on the worksheet.

This scheme offers many conveniences as a result of the repetitive nature of the application: 1) because the same data files are used over and over, they may be stored in a download module (or the computer) and loaded into the Polycorder whenever they are needed; 2) after the data are offloaded to a computer, they may be erased from the Polycorder file, retaining the blank data file in the Polycorder for reuse; and 3) automated data processing is optimized, thus the data can be transmitted to a computer and summarized in minutes.

Research Application

The above approach works well for repeatedly measured variables where the same data forms are consistently used. However, that is often not the case in research. Each study typically has one or more unique data files; the data files will usually be more complex, e.g. containing several columns of descriptors for block, treatments (in random order), and seedling number;

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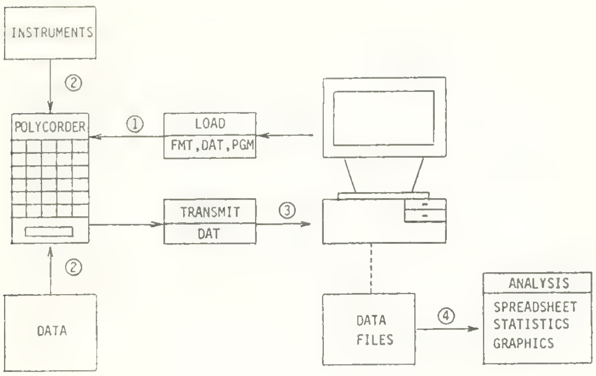
[3]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

there may be a need to append additional columns onto the original file for annual measurements; and some data types may be transmitted to the PDR via a serial port from a digital balance, calipers, area meter, porometer, or other device. The following diagram shows a typical data collection and processing scheme in research applications of PDR's:



The format and empty data files are more easily created on a computer, stored as ASCII files, then downloaded directly to the Polycorder (1). The format file can be written with EDLIN or any word processor that will output an ASCII file. The data file containing the descriptors (block, treatment, tree number, etc.) in the desired sequence can be "constructed" using Lotus 123, or can be created directly with certain statistical programs such as Minitab. The ASCII format and data files are downloaded to the Polycorder using a communications program. This step can be expedited by using a communications program that has versatile command and script file capabilities. An example is presented in Table 1.

Data are entered into the PDR through the keyboard (2) or by direct transmission from instruments (2). Direct transmission of data from instruments is very fast, but requires that a Polycode program be written to accept, manipulate, and file the transmitted data. For example, we weigh dried plant samples without removing them from the bags. Paper bags of the same size are surprisingly consistent in weight. We dry a group of empty bags along with our plant samples, determine an average empty bag weight, then enter that value into a Polycode program. The program subsets the measured weight from an alphanumeric string transmitted by the balance, subtracts the average empty bag weight, records the tissue dry weight in the data file, performs cursor movements, and provides file location prompts. This technique works well for samples that have a dry weight greater than 1 gram; the experimental error is no greater than that introduced by removing the plant samples from the bags to weigh them.

The completed data file is transmitted back to the computer (3), using a communications program. File redirection programs such as Dpath and File Facility are handy for organization purposes because they allow you to store data files in separate subdirectories on a hard disk, rather than storing them all in the same subdirectory with the communications program. The final step of the scheme shows the data files being imported into various spreadsheet, statistical, or graphics programs for analysis (4).

DISCUSSION

Portable data recorders have the potential to increase efficiency of data collection in a variety of applications. However, they are not for everyone. Converting to a different method

Table 1. A Crosstalk script file (*.XTS) for transferring files between a PDR and a microcomputer. The script file loads automatically when it is given the same prefix as the command file (*.XTK). The communication protocols used in the command file must match those of the PDR.

```
GO LOCAL
CLEAR
ASK Type L for Load, T for Transmit, E for Edit, or Q for Quit
JUMP DO-@
LABEL DO-Q
QUIT
LABEL DO-L
SCREEN D
CLEAR
LWAIT CHAR " "           ;insert mating call character sent by PDR, if used
SEND
RWIND
LABEL DO-T
SCREEN D
CLEAR
CA
WHEN " " ALARM NOW       ;insert end of file character sent by PDR
WAIT STRING " "          ;insert end of file character sent by PDR
CA -
RWIND
LABEL DO-E
RUN
```

requires an investment in new equipment, and time to evaluate the actual need for the device, to learn how to use it, to develop a system to apply it, and to train personnel to use it properly. Thus, there will be a start-up period before a net increase in efficiency is realized. You should be reasonably certain that using a PDR is justified before you make a commitment. Use of a PDR (and a computer for that matter) may well help you reach a higher level of technology, efficiency, and productivity. However, that is only achieved through learning, commitment, and adaptability.

In research applications, we find that using PDR's allows us to take more data than would otherwise be possible with available personpower. This is especially true when instruments are interfaced with a PDR. One person can take several times more data in a single day, with good precision and less fatigue. Most technicians are enthusiastic about using data collectors because they save time, and the person feels a sense of accomplishment for mastering the use of a sophisticated electronic tool. Because data entry and verification are eliminated, the technicians are relieved of those tasks, and the computer is freed for other uses.

In summary, PDR's are a cost-effective alternative to conventional data sheets for data collection and manual entry of data into a computer. Data collection time is about the same with a PDR, but the need for manually entering data into a computer and verifying them is eliminated. Other benefits are the opportunity to perform error checking in the field, interface with instruments, and obtain faster turnaround of completed data analyses. In general, if a PDR is used frequently, the labor savings will pay for the device in 1-2 years.

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Superabsorbent Hydrogels and Their Benefits in Forestry Applications[1]

Fernando Erazo[2]

Abstract.--Superabsorbent hydrogels applications for forestry use have been developed over the last few years and are now being used as soil additives in growing containerized seedlings and as "ROOT-DIP" prior to packaging and storage.

INTRODUCTION

AGLUKON AGRI-PRODUCTS is part of the worldwide group of Schering Agrochemical Companies.

In Europe, it is estimated that 60% of pine trees are affected by acid rain. Schering (AGLUKON S.D.) is the founding researcher company that in 1984 started and successfully developed products to prevent damage of acid rain in young and established pines.

In the U.S., Schering (AGLUKON) has been marketing agricultural superabsorbents since 1979. In 1982, we built the first U.S. synthetic hydrogel facility for agricultural applications. AGLUKON is the manufacturer of ROOT-DIP superabsorbents.

In 1987, AGLUKON will introduce, for trials, a specialty foliar potassium compound for hardening of seedlings. This could allow nurserymen to lift seedlings even if weather remains warm.

1. WHAT ARE SUPERABSORBENTS?

Crosslinked polymers that absorb and retain fluids hundreds of times their own weight, are call superabsorbents.

The ability to absorb and retain water and other fluids, has encouraged many a company to seek a variety of applications:

Health Care--Diapers, sanitary napkins

Industrial Use--Municipal water treatment, wipers, oil mudding

Agriculture--?

2. ADVENT OF SUPERABSORBENTS IN AGRICULTURE

It is difficult to believe that we are in the third decade of some form of superabsorbent usage. (See Table 1.)

3. TYPES OF SUPERABSORBENTS

The 1960's

In the early sixties, the Agricultural Research Group of Union Carbide already had developed a hydrogel that absorbed up to 40 times its own weight in water...this was a polyethylene polymer combined with sawdust... a soft gel designed to be mixed with soil, to improve water capacity and aeration of soil mixes. This was the first gel developed specifically for horticultural practices.

The USDA in Illinois then discovered that crosslinked acrylonitrile with corn starch could also absorb over 100 times its own weight in water. The USDA licensed several companies to produce such a superabsorbent gel. Most of these designed uses for health care, and some agricultural segments.

Several companies also produced cellulose gels, and research for synthetic hydrogels had begun.

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[1]Paper presented at the Intermountain Forest Nursery Association, hosted by the Oklahoma State Dept. of Agriculture Forestry Division, Oklahoma City, Okla. August 10-14, 1987.

[2]Fernando Erazo is President of Aglukon Agri-Products, Congers, N.Y.

TABLE 1.--TYPES OF SUPERABSORBENTS

Chemical Name or Ingredient	Market Application	Period
Polyethylene Oxide/sawdust	soil amendment	1965-1978
Polyvinyl Alcohol	diapers	1975-present
Acrylonitrile/starch	tampons, napkins	1979-present
	soil amendment	1966-1983
	planting seedlings	1978-present
Potassium Propenoate/Propenamide copolymer	soil amendment	1978-present
	gel seeding	
(Potassium Polyacrylamide/Poly Acrylate Copolymer)	plug-mix planting	1982-present
	root-dip	
Acrylic Acid (polyacrylates)	diapers	1981-present
	sanitary napkins	1982-present
	water treatment	1983-present
	soil amendment	1984-present
Acrylamide (polyacrylamide)	diapers	1983-present
	sanitary napkins	1984-present
	soil amendment	1983-present
Acrylic Acid/Acrylamide (combinations)	diapers	1985-present
	soil amendment	1985-present

the 1970's

The early products that combined a synthetic polymer with natural polymers penetrated on a small scale, several areas of horticulture and many trials were conducted in agricultural applications, including planting of bare-root seedlings.

In the late seventies, however, researchers in the U.S., Japan and England announced the discovery of different types of synthetic superabsorbents, which sought to eliminate the problems associated with natural polymers.

Most of these newly discovered superabsorbents found a home in the diaper industry, and only one in the U.S. built a facility and began application and product development solely for agricultural uses.

the 1980's

Several of the manufacturers of superabsorbents for diapers and municipal water treatments are now seeking to expand their market into all segments of agriculture.

Many of these products are not fit for our industry. Therefore, it is our responsibility to know why.

It is also our responsibility to recognize which of the superabsorbents are good for agricultural applications.

Proven technology has now been developed and is in place for specific segments of agriculture, horticulture, foresty. This technology application is based on the choice of a correct product for a specific application.

4. APPLICATIONS PRACTICED IN HORTICULTURE AND AGRICULTURE

Propenoate propenamide copolymers are successfully used as follows:

Soil Additive

-to increase water holding capacity
-to improve aeration and drainage of soil mix
-reduce irrigation frequency
-increase shelf life
-maintain moisture equilibrium

The superabsorbent must be able to release water when the moisture equilibrium of the soil changes, or as the roots need it.

Major uses are in container growing and tree and shrub planting.

Growing Of Transplant Plugs In The Greenhouse

The advantage is that the "chunks" of gel are carried from the greenhouse to the field in each plug, thus...

-not only has the grower received the benefit while growing the plug, but
-he can also eliminate transplant shock during transplanting operations

Fluid Drilling Or Gel Seeding Of Pregerminated Seeds

In this case, the superabsorbent gel must make a perfect suspension , soft, but consistent , to protect the delicate 2 mm seedlings while they are extruded to the soil.

Root Dipping Applications

It is now well proven that a major factor in field survival of bare-root seedlings is the proper treatment and handling of seedling roots prior to planting them. Root dipping with the correct gel will fulfill that need.

5. USE OF THE CORRECT SUPERABSORBENT IN FORESTRY APPLICATIONS

Soil additive for growing containerized seedlings.

Root dip spray for bare root seedlings, after lifting, prior to storage.

6. SOIL ADDITIVE FOR GROWING CONTAINERIZED SEEDLINGS

System

The small granules of superabsorbents are thoroughly blended into the peat mix prior to filling the plugs.

"Viterra" absorbs free water that is normally lost to leaching. As the "Viterra" granules expand, the soil volume increases and aeration and drainage improves. Each granule acts as a tiny water reservoir, replenishing moisture as the soil dries out, or absorbing excess moisture. Essentially, "Viterra" acts as a buffer in your soil, stabilizing the moisture levels for optimum root development.

Benefits

The small amount of superabsorbent will create optimum growing medium with consistent moisture equilibrium, resulting in a homogeneous size seedling which can reduce grading activity with less frequent irrigations.

An additional benefit is that the containerized seedlings already have hydrated gel "chunks" to protect against transplant shock, and give the forester a better stand.

Rates

Mix 1.5 lbs. of superabsorbent for each cubic yard of mix OR 1 oz. per cubic foot of mix.

7. ROOT DIP SUPERABSORBENT FOR BARE ROOT SEEDLINGS

A nursery can now choose the easiest, least messy, labor prompt and most effective method from the following:

a. root packing with peat moss
b. dipping in a clay slurry
c. spraying with ROOT-DIP superabsorbent

If we are concerned with field survival of bare-root seedlings, we must give their roots the best care and treatment available. ROOT-DIP will keep the roots in a moist condition, and will prevent root "dry-out" during storage and shipping.

How to use ROOT-DIP

Easy to use. There is no need for special equipment to produce a ROOT-DIP slurry suspension. Just add the correct rate of ROOT-DIP to water. Wait a few minutes to hydrate, and your ROOT-DIP treatment is ready!

Spray the bare-root seedlings with ROOT-DIP slurry.

The tiny water-laden gel particles will cling to the seedling roots, and will replenish moisture to the roots during storage and shippings.

Rates

One pound of ROOT-DIP for 33 gallons of water is sufficient to treat up to 15,000 bare-root seedlings, at an average cost of $.367/1,000 seedlings, or less.

8. BUT...

Let's remember that not all superabsorbents are the same. (See Table 2.)

In fact, ROOT-DIP superabsorbent is good for treatment of bare-root seedlings, but not good for treatment of baby diapers.

9. WHAT TO LOOK FOR IN A ROOT-DIP GEL

-Non-toxic by FHSA standards
-Non phytotoxic, must be inert
-Neutral Ph

Table 2.-- Comparison of "VITERRA" ROOT-DIP versus other super-absorbents.

SYNTHETIC SUPERABSORBENT MEASUREMENT TEST

National Tree Seed Laboratory
September 9, 1986

SCREENING FOR PARTICLE SIZE	ROOT-DIP	COMPETITOR
Sample	50 gr.	50 gr.
Over #20 screen	.19 gr. .3%	8.27 gr. 16.5%
Through #20 screen and over #40 screen	49 gr. 98%	35.75 gr. 71.5%
Through #40 screen (Dust)	.79 gr. 1.6%	5.89 gr. 11.8%
Lost in screening	.02 gr.	.09 gr.
ABSORPTION		
Superabsorbent Sample	.25 gr.	.25 gr.
Water sample	300 ml.	300 ml
Hydrated Gel Particles	86.67 gr.	49.87 gr.
Excess Water Vacuumed off	205 ml	243 ml
Excess Water Lost in Filter	8.58 ml	7.38 ml
Absorption Rate	346:1	198:1
CHARACTERISTICS		
Particle Size	Excellent	Poor
Suspension	Good	Poor
Gel Strength	Soft	Hard
Water Absorption	Good	Poor

Dustless--Superabsorbent dust added to water can become a "coating." If this coating dries out, it can act as a barrier, sealing off oxygen to the roots.

Uniform particle size--In order to obtain (-20+35) a uniform, stable suspension, with sufficient hydrated granules, to adhere to the seedlings...when the granules are too large, they will fall off roots.

-Propenoate-propenamide copolymers with the correct rate of potassium polyacrylate and polyacrylamide.

-Absorption capacity should be no more than 400 times its own weight, and no less than 300 times.

-The absorption capacity and size of the granule determine the weight of the hydrated gel that clings to the roots.

-ROOT-DIP superabsorbent should be coated with hydrophobic adjuvant to avoid lumping during hydration.

-Should be easy to use.

-The physical-chemical properties of the ROOT-DIP gel should ensure that moisture is released from the gel to the roots when the moisture equilibrium of the roots need it. (diaper gels hold and retain water, but do not release it)

-When dry, the ROOT-DIP gel looks like a white crystal. It is odorless, free flowing.

-When hydrated, the ROOT-DIP gel should not be rubbery or hard. To be sure that moisture can be released, gel should be on the soft side.

-Hard gels will fall off the seedlings during handling.

-The ROOT-DIP gel must be supported by good quality control and a company that is in the agricultural business, knowledgable and responsive to grower needs.

10. THE FUTURE

The future of superabsorbents in forestry is bright.

The aim will continue to be to encourag governments, industry, and the public in general, to forest the land, to preserve it and enjoy it, and in so doing, to utilize safe proven products at an economical cost.

Our responsibility as nurserymen, is to be there and to utilize the best methods available to grow the best seedlings.

Organic Matter: Short-Term Benefits and Long-Term Opportunities[1]

John G. Mexal and James T. Fisher[2]

Abstract: Crop benefits derived from organic amendments to southern nurseries appear minor and limited by the rapid rates of OM decomposition common to the region. This paper reviews a case study and related studies to examine the actual and potential benefits of amendments as determined by the kinds, amounts and frequencies of applications. It is possible to increase the stable fraction of OM in nursery soils and, potentially, to improve seedling growth and yield. However, it will be necessary to apply amendments more frequently than conventionally done.

INTRODUCTION

Nursery managers believe organic amendments are essential to efficient nursery production in southern regions. This belief is at least partially derived from the manner in which seedlings are harvested. In contrast to most agricultural crops, nursery seedlings are harvested as whole plants, and only negligible amounts of post-harvest crop residues remain in the soil.

Clearly, organic matter (OM) is essential for efficient crop production. It acts as a reservoir of nutrients that become available slowly as decomposition proceeds. In addition, OM improves soil cation exchange capacity (CEC). Consequently, more nutrients are retained against leaching in soils high in OM. OM also buffers the soil against abrupt changes in soil acidity that can occur when fertilizers such as ammonium sulfate are applied.

OM improves water infiltration and augments net soil moisture retention. These benefits are important for soils that tend to crust or that have high salt content, esp., sodium (DeBano, 1981). OM adsorbs the cations and prevents flocculation of clay particles. Certain types of OM can suppress soil-borne plant pathogens such a *Pythium* and *Phytopthora* through the release of fungicides. OM also can alleviate the symptoms of certain abiotic diseases caused by herbicides or excess salts.

Nurseries apply a variety of organic amendments to maintain soil OM (Davey, 1984). In the South, conifer sawdust and bark are commonly applied because of the abundance of wood mill residue. Other OM amendments include

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[1] New Mexico State University Agricultural Experiment Station Paper No. 290., presented at the 1987 Inter-Mountain Nursery Conference, Oklahoma City, OK, August 10-14, 1987.

[2] Authors are, respectively, Assoc. Professor and Professor, Dept. of Agronomy and Horticulture, New Mexico State University, Las Cruces, N.M. 88003

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hardwood sawdust and bark, municipal waste and animal waste. Use of these materials is usually limited by local availability. For example, fish waste or horse manure is applied if the nursery is near a hatchery or racetrack, respectively. Transportation costs generally preclude nurseries from using northern peat moss.

Green manures or cover crops do not add to the stable organic fraction of the soil. In fact, when a cover crop is turned under, soil OM may actually decrease after a brief period (Pieters and McKee, 1938). Essentially, the stimulation of microbial activity created by the addition of a readily decomposable food supply can cause a net reduction in the steady state level of soil OM. However, cover crops are not without merit; they can be used effectively to reduce wind erosion and to eliminate plow pans.

Nursery soil OM depends on location and soil type. Nurseries in the Northwest tend to have OM levels greater than 3 % (Davey, 1984). However, nurseries in the South average less than 3 % soil OM (South and Davey, 1982) and those on sandy or sandy loam soils have less than 1.5 % OM. Nurseries in the Southwest (New Mexico and Oklahoma) average about 1 % (Myatt, 1980; Windle, 1980).

The objective of this paper is to discuss the short-term response of nursery soil to organic matter additions using the USFS Albuquerque Tree Nursery as a case study, and to discuss the long-term opportunities to improve crop production through better OM management in nurseries.

ORGANIC AMENDMENTS APPLIED TO A SOUTHWESTERN NURSERY: A CASE STUDY

Treatments

Before fumigation for the 1984 crop, approximately 12 mm of OM was incorporated into the surface 15 cm. The OM treatments included gamma-irradiated sewage sludge, pine bark, pine sawdust, horticulture grade peat moss and no OM. Treatments were added at the rate of 67 t/ha, except sawdust that was added at 43 t/ha. Soil and seedling nutrient status were followed over the course of the production cycle (1.5 growing seasons), and seedling yield and morphology were determined November 1985.

Results

The OM additions caused immediate but short-term changes in soil OM and nutrient availability. Soil OM (particles < 2 mm) was affected most by sawdust (Fig. 1). The sawdust plots had an OM content of nearly 4 % about 2 months after application. Sludge increased OM less than 1.0 %. Particles > 2 mm were still visible in the soil, but these are not measured in standard OM determinations. In all likelihood, particles this large neither stimulate soil microbial activity nor directly influence seedling nutrition.

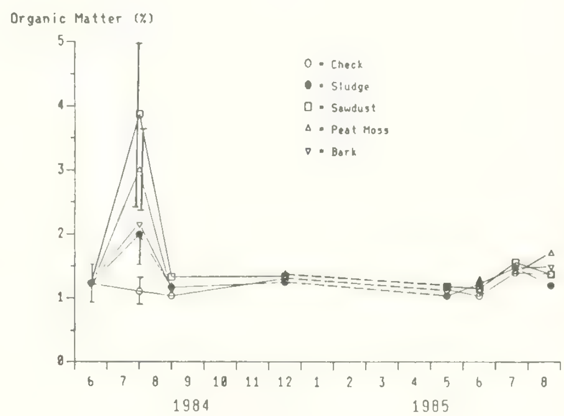

Figure 1.--Effect of organic amendments on soil test OM at the Albuquerque Tree Nursery. Only the peat moss treatment is significantly different from the control (α = .05) for the July 1984 sample only. Vertical bars represent $\pm$ 1 S.E. of the mean.

The response of soil nutrients to OM was also short-lived. Only sludge increased soil NO_3 (Fig. 2A). Bark and peat moss had no detectable effect, but sawdust caused rapid immobilization of NO_3. By August, NO_3 in the sawdust plots was 1 ppm compared to 28 ppm for the control. By December, all plots had only 1 ppm NO_3. Five applications of urea (53 kg/ha) failed to increase soil NO_3 to more than 20 ppm, and by August 1985, soil NO_3 returned to 1 ppm, the pre-application level.

Other nutrients (P,K and Fe) behaved similarly (Fig. 2B-D). Generally, soil nutrient levels increased shortly after OM application, and decreased over the remainder of the rotation. For example, K decreased from 145 ppm before sowing to about 60 ppm 14 months later. Again, sludge increased soil K slightly early in the season, while sawdust decreased soil K slightly. Bark and peat moss did not alter nutrient levels. All treatment differences disappeared by December 1984.

OM amendments had no effect on seedling yield, height, caliper or fresh weight. However, seedling R/S was significantly reduced by bark, sludge and peat moss (Table 1). Seedling shoot fresh weight was positively correlated with increased soil nutrient levels brought about by the OM additions. However, R/S and shoot fresh weight were only sightly affected by OM addition. Nevertheless, the responses detected do indicate that OM amendments can alter seedling morphological development. However, additional work is needed to adequately explain this relationship.

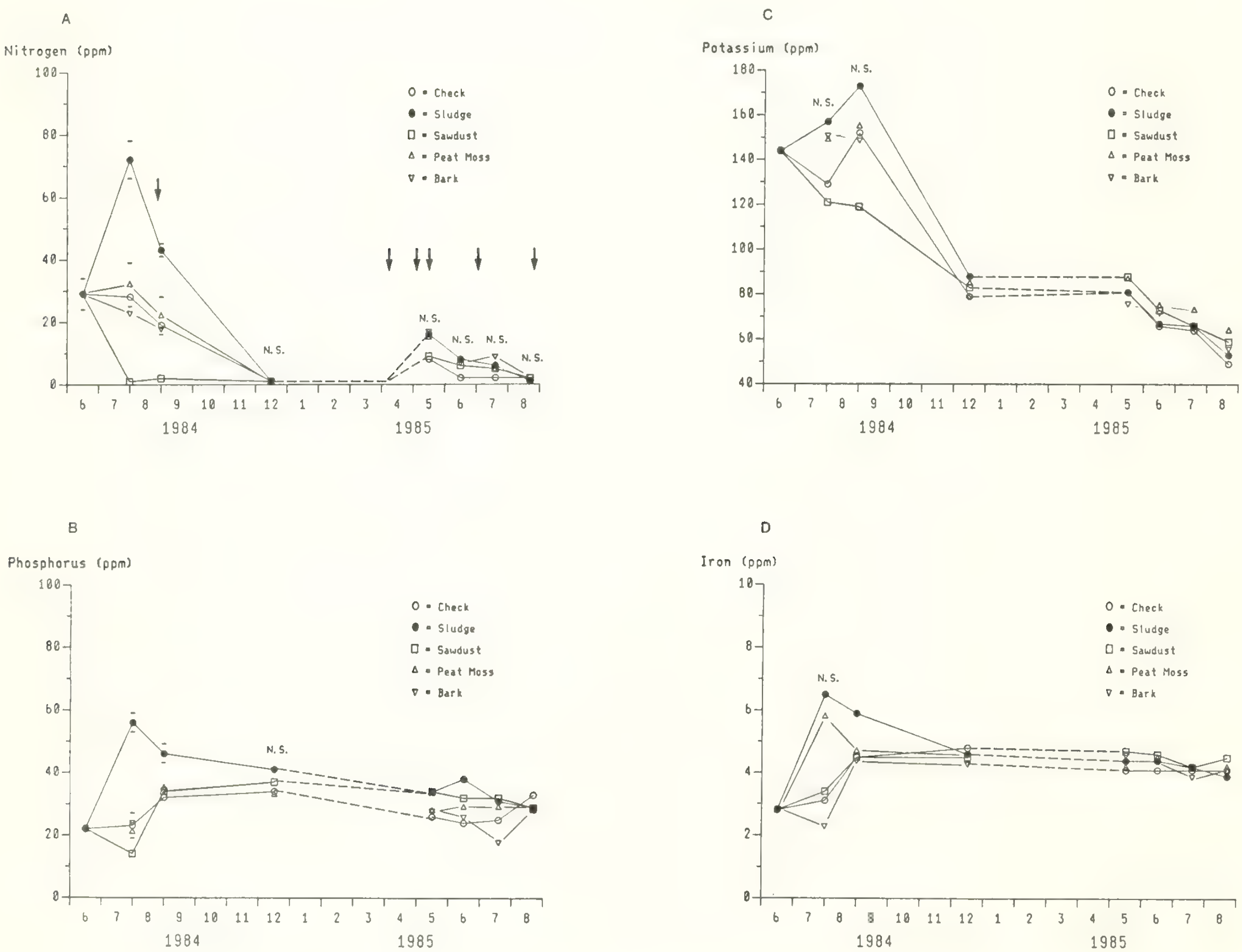

Figure 2.--Effect of organic amendments on soil test nutrient contents at the Albuquerque Tree Nursery, where A = nitrogen, B = phosphorus, C = potassium and D = iron. Arrows in Fig. 2A indicate applications of 53 kg/ha of urea. Vertical bars represent $\pm$ 1 S.E. of the mean; N.S. = not significant.

Table 1.--Effect of different organic amendments on 1.5 + 0 ponderosa pine seedling morphology.

Treatment	Height (cm)	Caliper (mm)	Fresh Weight (g) Shoot	Root	R/S
CONTROL	10.5	3.4	3.84	1.94	.56
SAWDUST	9.7	3.4	3.59	1.74	.54
BARK	11.4	3.4	3.98	1.86	.51 [1]
PEAT MOSS	10.4	3.2	3.66	1.72	.51 [1]
SLUDGE	11.2	3.5	4.16	1.89	.50 [1]
	N.S.	N.S.	N.S.*	N.S.	

1 Significantly different from Control (d=.05)

* Correlated with Nov. 1985 Soil [P] and [N]

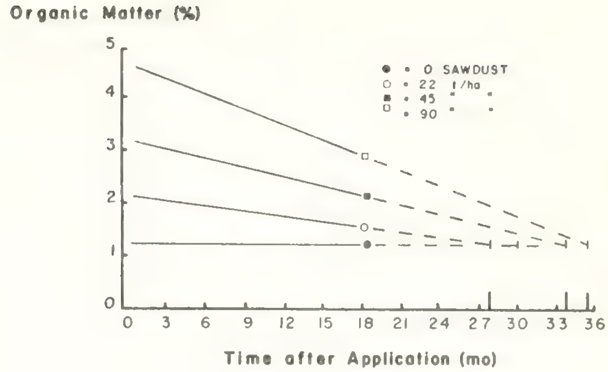

Figure 3.--Effect of rate of application on the decomposition of sawdust in a Florida nursery (after Munson, 1983). Return to ambient level is extrapolated to be 28 mo for 22 t/ha, 34 mo for 45 t/ha and 35 mo for 90 t/ha.

DISCUSSION

Although not encouraging, our results generally agree with studies conducted in the southern United States. Saloman (1953) treated soil with various levels of sawdust and found no change in soil OM and no improvement in plant growth. Similarly, the addition of sewage sludge to a nursery soil in the Northwest resulted in few improvements among the conifer species tested, and results from the outplanting trials were generally negative (Coleman, et al., 1986). However, Berry (1980) found that pine responded positively to the addition of sludge in a Florida nursery. Seedlings responded best to sludge applied at rates of 60-136 t/ha. The 67 t/ha treatments employed in our study failed to promote a similar response in ponderosa pine seedling growth.

Long-Term Opportunities

Many studies, including this one, examine the short-term response of soils, and generally report the response of one seedling crop to a single OM addition. Such studies point to the rather abrupt changes occurring in amended soils. Within 1 year, more than 60 % of the OM added will decompose, and about 90 % will be decomposed in 2 years or less (Davey, 1984). Davey and Krause (1980) believed the stable fraction of soil OM could be increased about 0.1 % by adding 20 t/ha. However, Munson (1983) found peat moss decomposed more readily as application rates were increased. Munson found OM levels in the soil would return to ambient levels in 28 months after the addition of 22 t/ha, and 34 months after the application of 90 t/ha (Fig. 3).

Apparently, amendments would have to be applied more frequently than once every 3-4 years to cause a net increase in stable soil OM.

A similar conclusion can be drawn from May and Gilmore (1984) who applied OM repeatedly in a loblolly pine nursery during a 6-year period. Sawdust was applied at 33 or 66 t/ha rates repeated two, three or six times over the the course of the study. The maximum rate (66 t/ha applied every year) added a total of 396 t/ha of organic matter and effectively increased soil OM from 1.9 % to 3.2 % (Fig. 4). The OM level of the control plots was not altered over the 6-year period, despite the harvest of six seedling crops. Soil OM responded in a linear manner to the amount applied and to the frequency of application. The positive effects reported by May and Gilmore contrast sharply with studies employing single applications of comparatively large amounts of organic matter, and consequently reporting no practical benefits (e.g., Munson, 1982).

A relationship often ignored in the United States is the efficacy of inorganic fertilization as a substitute for organic amendments. Most information on this subject comes from the United Kingdom where the climate is much less severe than in the South or Southwest. Nevertheless, trials conducted in the United Kingdom have shown that inorganic fertilization can serve as a suitable replacement for OM.

However, in certain tests, the best treatment was a combination of inorganic fertilization and OM addition.

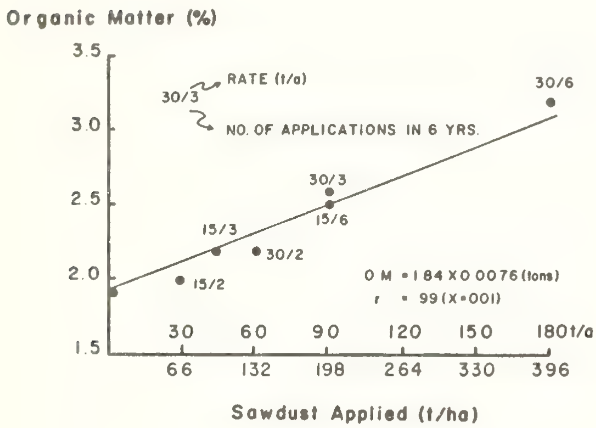

Figure 4.--Effect of amount and frequency of application of sawdust on OM content in a Alabama nursery soil (after May and Gilmore, 1984). The application rate was 16 and 33 t/ha applied either 2, 3, or 6 times in 6 years.

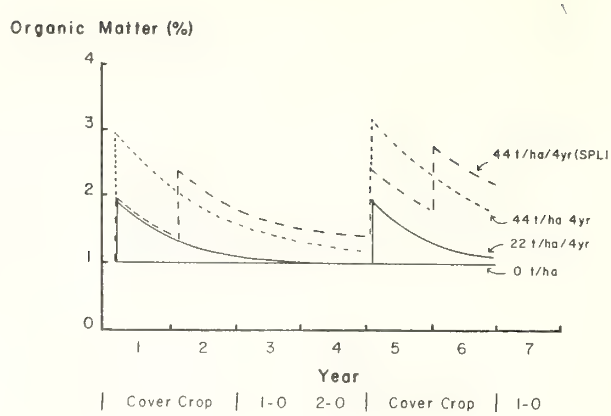

Figure 5.--Hypothetical trends in soil OM following different schemes of addition (adapted from Davey and Krause, 1980)

Future Prospects

Few studies have actually demonstrated that OM additions applied at conventional frequencies significantly improve nursery soils, seedling crops or profit margins. Present day practices will not significantly increase soil OM levels, and crop benefits will be of minor importance (see Fig. 4). More specifically, many nurseries apply 22 t/ha every 3 or 4 years before sowing 2+1 or 2+2 crops, respectively. Clearly, such practices will not significantly improve crop yield (Fig. 5). Within 4 years, the additional OM will decompose and will not cause a net gain in steady-state soil OM. Therefore, to significantly increase the stable OM fraction, at least 22 t/ha should be applied years 1 and 2 before sowing a cover crop.

Frequent applications of organic amendments will benefit some nurseries more than others. Among the problem soils potentially benefitting greatly from frequent applications are those with comparatively low water infiltration rates. As seen in Fig. 6, OM level significantly affects water permeability. In the Southwest, the occurrence of torrential rains and the need to control evaporative losses are related concerns. OM should also increase soil nutrient retention and reduce the occurrence of crop maladies associated with salts and pesticides, as numerous studies of low-OM soils have shown.

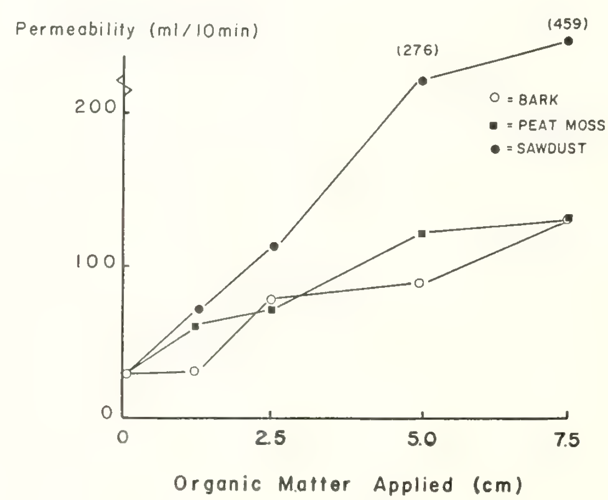

Figure 6.--Effect of type and amount of OM on water permeability (after Pokorny, 1982).

CONCLUSIONS

Extrapolations from our work and the study of May and Gilmore (1984) suggest that nursery soil OM can be raised to higher stable levels, even in regions where high temperatures and irrigation are conducive to rapid OM decomposition (Munson, 1982). Also evident is that present day amendment practices would have to be revised to provide the benefits desired.

Although OM amendments theoretically can improve nursery yield, field data for this region are inadequate to confidently predict economic benefits. For the present, we recommend nurserymen in the South and Southwest either apply no OM, or at least 2 applications of 22 t/ha over a 4-year rotation. Additionally, nursery managers should not overlook the opportunity to add OM before sowing the seedling crop, or the benefits derived from mulching with organic materials such as bark.

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The Trees Unlimited Program: An Experiment in Establishing Seedling Plantings[1]

Robert C. Oswald[2]

Abstract.--Trees Unlimited is a pilot project formed in 1985 to provide an integrated, year-round program of planting design, seedling planting, and maintenance to rural landowners in northern Colorado. It is a nonprofit program which sells seedling survival products and total tree care services associated with the establishment of conservation plantings.

INTRODUCTION

Trees Unlimited was formed in 1985 through funding by an association of four soil conservation districts in the northern front range area of Colorado and the State Soil Conservation Board. The intent was to provide not only promotion and sales of seedling trees in the area but also to provide to the rural landowner a source of planning and design assistance, site preparation, planting, and other tree care services associated with the establishment of seedling conservation plantings.

The program operation is similar to that of a small business. Although it is nonprofit, it must generate its own operating budget. Therefore, there is a fee charged for services besides the price of goods and materials sold.

ORGANIZATION

Trees Unlimited is overseen by a board consisting of a member from each of the four soil conservation districts involved. There is a program manager who reports the progress periodically to the board but operates the program mostly autonomously.

Cooperating with the program are the local field offices of the Colorado State Forest Service (CSFS) and the USDA Soil Conservation Service (SCS). These offices actively refer interested parties to Trees Unlimited. These same district offices also help support the program through lending field assistance, office and storage space, and seedling storage facilities during the spring.

The original targeted market for sales of seedling conservation plantings was the large number of agricultural producers in the area. However, due to various factors, the majority of plantings sold during the last two years has been to owners of small rural acreages. Because the area is situated near several population centers, there is an abundance of the "hobby farms" in the 1,500 square miles that Trees Unlimited serves.

PLANTING SERVICES

Trees Unlimited tries to make available a wide variety of products and services for its customers. Various combinations of materials and services are needed in each different situation, and assistance is given to the landowner to decide which practices and plants are appropriate or needed. In these seedling plantings, the plant material is typically a small percentage component of the total program cost. Overall, labor costs are the largest portion, followed usually by cost of drip irrigation materials. Some representative prices of services are shown in table 1.

The program manager will perform an initial site visit and landowner consultation, design a planting and/or irrigation plan, offer several site preparation and weed control methods, and detail all of these prices in an itemized bid. Based on the landowner's budget and the need/desire for a planting, he or she will decide on the size of planting and level of service to be implemented.

Upon signing the contract agreement and receipt of the initial payment (depending upon the season), work can begin immediately. Actual installation of tree shades can be seen in figure 1.

The types of conservation plantings Trees Unlimited has implemented include field and farmstead windbreaks, wildlife habitats, Christmas tree plantations, and fruit orchards. The designs conform to SCS and/or CSFS specifications.

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[1]Paper presented at the Intermountain Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

[2]Robert C. Oswald is the Tree Program Manager of Trees Unlimited, Longmont, Colorado.

Table 1.--Average prices charged to planting customers based on a planting of 200 to 300 trees and shrubs.

Services and products	Price charged per tree[1]
Site visit	0
Planting and/or irrigation design (total)	75.00
Site preparation--Simazine application	1.10
Site preparation--Rototilling	.80
Plow & disk (CSFS rented equipment)	1.80
Planting (manual or by machine)	1.25
Fertilizer tablet, installed	.25
Plastic rabbit guard, installed	.80
Wooden tree shades, installed	.80
Drip irrigation system, installation	1.00
Drip irrigation system, materials[2]	2.20
Wood chip mulch, installed	1.10
Polypropylene mulch, installed	3.90
Herbicide application, Roundup	.50
Insecticide spray	.40

[1] These prices are the base amount for work within a 20-mile radius of Ft. Collins or Longmont, Colorado. For each 10 miles beyond the radius, the base price is increased 20%. These prices are for services to seedling plants.

[2] This is an estimate based on actual amounts of materials used on past plantings; used here for preliminary estimate.

Figure 1.--Installation of wooden tree shades on a 3-row windbreak near Boulder, Colorado.

Another important form of conservation in Colorado is water conservation. On a tree planting great amounts of water (plus time, water costs, and pumping costs) can be saved through employing a drip irrigation system. Trees Unlimited stocks a full line of materials for sale and installation. This accounts for a large percentage of material sales annually.

Providing these services on most of the plantings has yielded survival rates, on an average, of greater than 95% into the second year. An example of a high level of service, i.e., combining several products to contribute to seedling survival, can be seen in figure 2.

Figure 2.--Close up of a pinyon pine seedling, showing plastic rodent guard, tree shade, drip irrigation pipe, and wood chip mulch.

PROGRAM PROMOTION

Trees Unlimited has a small advertising budget and relies in large part on the cooperating agencies' active referrals for business. The program also utilizes press releases and news announcements through the local radio stations and newspapers. Booths at country fairs shared with soil districts have helped for exposure. The soil districts and agency district offices also keep Trees Unlimited's brochures to hand out. Mass mailing to targeted areas, telephone contacts, and site visits make up most of the winter duties.

INVOLVEMENT WITH NURSERIES

Trees Unlimited contracted for planting almost 8,000 seedling trees in 1987, both bareroot and containerized. The bulk of these were purchased from the CSFS Nursery in Ft. Collins,

Colorado. Most seedlings sold by this nursery are either picked up by the customer on specific days or shipped out during a short time period each spring. With a schedule such as this, it might be inconvenient, if not impossible, for a program such as Trees Unlimited to interact with a nursery if the nursery policy were inflexible. Due to the nature of Trees Unlimited's business, planting time is extended, usually filling all of April and May. The trees must be stored during that period, yet be available to the planter every day. A workable arrangement has been made for storage and pickup, both from the nursery and from a CSFS district office 50 miles away, which provides similar storage facilities.

Other seedling survival products and chemicals are often purchased through a few of the local commercial nurseries.

Occasionally, larger planting stock is desired by the customers, and that is available everywhere. For the most part, the seedling-size planting material has the best combination of hardiness, vigor, size, ease of planting, and affordability.

THE FUTURE

As all of the people involved with Trees Unlimited agree, this is a program which is valuable and necessary in this area. It fills an important niche, providing the link between the seedling producer and consumer. It is a new program and will continue to depend on all of the involved parties to promote it. It is not a well-known name yet, and most potential customers do not know such a program exists. For that reason, it is felt that if this type of "total tree care" program were to be initiated in any certain area, it had best be allied in some way to an existing, known channel or outlet of seedlings. Publicity is usually the limiting factor to growth of a worthwhile business, and the cooperation and support of the area agencies are essential to the success and growth of such an experimental program.

The Potential of Soil Solarization in Nurseries to Control Soilborne Diseases[1]

Kenneth E. Conway[2,3]

Abstract.--Use of clear polyethylene sheeting to heat soil, through the technique called soil solarization, is being evaluated as a method to control soilborne pathogens at the Oklahoma Division of Forestry Nursery and at Stillwater, OK. Studies are directed at the effects of solarization on population densities of *Pythium* spp., *Macrophomina phaseolina*, and *Sclerotium rolfsii*. Soil temperatures under polyethylene sheeting during August-September at the Stillwater location reached maxima of 10 to 12 C greater than bare ground controls.

INTRODUCTION

Soilborne diseases incited by several genera of fungi can be economically destructive in a forest nursery. Pathogens of particular importance in Oklahoma are: *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii*, and *Macrophomina phaseolina*. Techniques used to control these pathogens have included crop rotation, fungicides (seed treatments, broadcast applications, and drenches), and soil fumigation. Each has its limitations due to the wide host range of soilborne pathogens, environmental contamination, or economics. The use of thin, clear polyethylene sheeting to transfer solar energy to soil to increase soil temperature is an alternative technique that needs to be investigated for use in the nursery.

This technique is called soil solarization and is based on our knowledge of thermal inactivation of soilborne organisms (Table 1). A 30 minute exposure to temperatures of 66 C will destroy most pathogenic bacteria and fungi. Pullman, et al. (1981) explored the relationships between increased temperatures and length of exposure to those temperatures on the survival of several soilborne fungi. Temperatures of 37 C for 18-28 days were needed to reach LD_{90} levels (90% reduction in populations) for *Pythium ultimum* and *Verticillium dahliae*. However, when temperatures were increased to 50 C, LD_{90} levels were achieved in 27-33 minutes. Therefore, lower temperatures can reduce populations of soilborne pathogens, but longer exposure times will be necessary.

Maximum soil temperatures of 60 C have been reported at depths of 5 cm in soil using solarization (Pullman, et al. 1981). However, these maxima are attained for only short periods of time. Reduction of population densities of soilborne pathogens is more realistically achieved by increasing soil temperatures 5 to 10 C above normal for an extended period of time. The effect of solarization on soilborne pathogens is a chronic effect that weakens and debilitates the survival structures (conidia, sclerotia, etc.) of these fungi. Other soil organisms are more thermotolerant and are not affected by solarization. These residual organisms multiply and prevent the recolonization of soil by the pathogen after solarization.

Table 1.--Temperatures required to inactivate pests in compost soils[a]

Pests	Temperatures[b] (F°)	(C°)
Nematodes	120	49
Damping-Off Organisms	130	54
Most Pathogenic Bacteria and Fungi	150	66
Soil Insects and Most Viruses	160	71
Most Weed Seeds	175	79
Resistant Weeds and Viruses	212	100

[a]Modified from Baker and Cook, 1974
[b]Temperatures maintain for a minimum of 30 mimutes

Soil solarization has been used successfully

[1]Paper presented at the 1987 Intermountain Forest Nursery Association Meeting. [Oklahoma City, Oklahoma, August 10-14, 1987].
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[3]The interest and support of the Oklahoma Department of Agriculture, Division of Forestry, Oklahoma City, is gratefully acknowledged.

to control a number of pathogens in various cropping systems (Conway, et al. 1983; Grinstein, et al. 1979; Jacobsohn, 1980; Katan, et al. 1983). Other research has indicated control of nematodes, weeds, and growth enhancement of crops planted in solarized soil (Heald and Robinson, 1987; Jacobsohn, et al. 1980; Grinstein, et al. 1979; Stapleton and DeVay, 1984). There have also been studies in which control of soilborne diseases was not achieved, particularly for Macrophomina phaseolina (McCain, et al. 1982; Mihail and Alcorn, 1984). Charcoal root rot, incited by M. phaseolina, has been a severe problem in southern tree nursery production. Unfortunately, reports on the use of solarization in forest nurseries are very limited. Hildebrand (1985a, 1985b) used soil solarization to reduce levels of Pythium and Fusarium spp. and weed seeds in Colorado and Nebraska forest nurseries. She estimated that, compared to chemical fumigation, solarization saved approximately $350.00/A in production costs.

In order to evaluate soil solarization as a technique to control soilborne diseases, experiments were initiated in 1986 at the Oklahoma Forestry Division Nursery at Washington, OK, by Mr. Mark Miles, a graduate student in the Department of Plant Pathology at Oklahoma State University. Additional experiments were performed at Stillwater, OK. Although much of this work is preliminary and will be used for Mr. Miles' M.S. thesis, a generalized overview of the research is presented below.

METHODS

Previous work (Conway, unpublished) has indicated that Pythium irregulare and Fusarium spp. were the primary soilborne pathogens at the Forest Nursery. Recently, stunted sycamore and Virginia pine seedlings were removed from the Nursery and isolations from the roots indicated that M. phaseolina was also an active pathogen. At Stillwater, populations of Sclerotium rolfsii and M. phaseolina have been documented in our apple seedling nursery (Conway and Tomasino, 1987; Tomasino and Conway, 1987). To ascertain the effectiveness of solarization, populations of Pythium spp. and M. phaseolina at the Forest Nursery, and of S. rolfsii and M. phaseolina at Stillwater will be enumerated before and after solarization.

Solarization experiments were performed at the Forest Nursery during April-May 1986 and August-September 1987. Experiments at Stillwater were conducted during August-September 1986 and 1987. In 1986, temperature data were collected through use of a system developed by Dr. V. Pederson, North Dakota State University. The computer program was modified to allow for 22 separate temperature probes.

Prior to placement of the polyethylene sheets, soil samples were randomly removed from all plots and stored at 4 C. Soil was bulked and thoroughly mixed before subsamples were removed. Population densities were determined for Pythium spp. and M. phaseolina using selective media (Conway, 1985; Campbell and Nelson, 1986). At Stillwater, spun-bound polyester packets containing 50 sclerotia of S. rolfsii were placed at 0, 5, 10, and 15 cm depths in soil to be solarized or used as controls. All soils were moistened prior to solarization. At Stillwater, drip irrigation was installed beneath the polyethylene sheets. Temperature probes were buried at 2, 4, 12, and 20 cm depths in soils of both solarized and control plots. The computer was programmed to record input from each probe every 30 minutes. Polyethylene sheets (4 mil thick) were applied to the plots using a mulch-laying apparatus. Appropriate sections of the polyethylene sheet within the row were removed to provide for control plots. Solarization lasted for approximately 6 weeks and soil samples were, again, randomly collected to determine densities of selected pathogens. Packets containing sclerotia of S. rolfsii were also removed, at that time, and percent viability was determined.

RESULTS AND DISCUSSION

Weather during April-May 1986 at the Nursery was unusually cloudy and greater than average precipitation occurred. On clear days, soil temperature at a depth, of 4 cm in solarized plots reached 49-50 C with a daily average of only 4 hr during which temperatures were greater than 37 C. Nonsolarized soils at the same depth attained temperatures of only 24-32 C. Population densities of selected fungi have been determined but differences among treatments have not been analyzed.

At the Stillwater location during August 1986, solarized plots reached temperatures of 57 C, with 6 to 7 hr greater than 45 C, at 4 cm depths. Non-solarized soils reached a maximum of 45-46 C. Packets containing sclerotia of S. rolfsii were retrieved from the soil after 4 weeks. Viability of sclerotia was determined by placing sclerotia on moistened filter paper in petri dishes and observing germination. No significant differences in viability between solarized and non-solarized soils were found at that time.

Soil solarization will not be a panacea for all nursery problems related to soilborne fungal pathogens, nematodes and weed seeds. Problems of polyethylene residue are similar to those involved with the use of chemical fumigants. Another concern is that soil solarization may not be effective in reducing population densities of particular fungi, such as Macrophomina phaseolina. In order to study this further, we have initiated laboratory experiments to determine the thermal death points in soil of Pythium irregulare isolated from the Nursery and isolates of M. phaseolina from several different hosts. Analysis of these data will enable us to make predictions regarding the effectiveness of solarization in the control of these pathogens.

To improve the effectiveness of soil solarization, future research should involve the integration of solarization with biological control agents (Elad, et al. 1980), the use of crop residue amendments (Ramirez-Villapudua and Munnecke, 1987), and the use of ammonia-based fertilizers. Data should be collected on the total effect of solarization and should include reductions in pathogen (including nematodes), weed and insect population densities.

Although our work is preliminary, we feel that we are in an exciting area of research, one that may have very real benefits for nursery production and management.

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Seedling Production at Oklahoma Forestry Division Forest Regeneration Center[1]

Clark D. Fleege[2]

The Oklahoma Department of Agriculture's Forestry Division has been supplying tree seedlings for conservation plantings since 1927. The Forest Regeneration Center near Goldsby distributes 4 - 4½ million seedlings annually. This includes bareroot one year old hardwoods, bareroot one and two year old conifers. The Division also manages a southern pine seed orchard.

The Oklahoma Forestry Division has been growing and distributing tree and shrub seedlings for Oklahoma's private landowners for almost as long as it has been in existance. From a meager beginning at Stillwater (in northcentral Oklahoma) in 1927, Oklahoma's State Tree Nursery moved first to Stringtown in 1938, and then to its present location south of Norman in 1945.

The Forest Regeneration Center at Washington produces hardwoods and conifer seedlings. It was formerly one of two nurseries operated by the Forestry Division. From 1949 until 1977, the Division grew southern pine seedlings at its nursery in southeast Oklahoma. Because of the need for modernization, and the high cost of operating two nurseries, a decision was made to contract the production of southern pine seedlings to the Weyerhaueser Company nursery in southeast Oklahoma.

The purpose of the Regeneration Center is to provide Oklahoma's private landowners with quality tree and shrub seedlings for planting on their lands. These seedlings are sold state-wide for a variety of purposes. Including wildlife habitat improvement, windbreak establishment, fuelwood, postlots, erosion control plantings, Christmas trees and timber production.

The Regeneration Center had 65 acres under production. Currently we produce 20 species of hardwoods and 9 conifer species. Our annual production is 4 to 4½ million seedlings. Currently the Forestry Division contracts with Weyerhaeuser to produce one year old improved loblolly pine seedlings. We also contract with Colo-Hydro of Longmont, Colorado for the production of conifer tublings used for planting on selected shallow, droughty soils of western Oklahoma.

The soil is a sandy loam "second-bottom land" soil, slightly basic. Each year we have soil samples analyzed through the State University of New York and amend each field accordingly to reach optimum nutrient levels for seedling production. For example, we will add sulfur to lower ph on specific fields; and manure and sawdust on every field to raise organic matter and improve soil texture. Fields that are not in crop production are planted to sudan grass cover crop in the spring. The cover crop will be mowed regularly throughout the growing season. Prior to winter the cover crop will be plowed and the field will be prepared for a spring planting. Generally, we have a field in cover crop every other year. We have two wells that pump to a 210,000 gallon storage tank from which all field irrigation is pumped. The entire nursery can be irrigated through a network of underground mainlines and field groundlines.

The seed for producing our crop is either collected from proven quality local Oklahoma sources; or purchased from reputable seed dealers, source-identified.

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[1]Paper presented at the Intermountain Forest Nursery Association, 1987 annual meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

[2]Clark D. Fleege, Nursery Superintendent, Oklahoma Department of Agriculture, Forestry Division.

We have been working closely with the Soil Conservation Service/Plant Materials Centers and Oklahoma State University in identifying those varieties that will exhibit specific traits deemed desirable, such as faster growth rate, drought-tolerance, frost-hardiness, disease-resistance, etc. Several varieties have been identified and seed production areas of those varieties have been established near the Regeneration Center. All seed is processed and stored at the seed extraction building.

All the hardwood species we produce are one year old seedlings. Seven species are fall or winter sown, and the remainder are stratified and planted in the spring. Because of our longer growing season, some species can become quite tall. For example it is more the rule than the exception for black locust sown in mid-June to be seven feet tall by October with little if any irrigation or fertilization. Of the nine species of conifers we produce, six are spring sown, two year old seedlings. Through fumigation and proper soil management we anticipate producing our improved Virginia pine and limited quantities of improved loblolly pine in just one season. The remaining conifer, bald cypress, can easily reach plantable size in one season. Immediately after the beds are sown, we apply a light layer of fine sawdust followed by a layer of hydromulch. This is done to help retain soil moisture, reduce soil temperatures and prevent "wash-out" in the event of severe spring showers.

Weeds are fierce competitors for soil moisture and nutrients. We try to maintain a weed-free nursery through the use of registered herbicides, mechanical weeding machines and seasonal labor. Over the past 10 years we have been working with State University of New York and Dr. Larry Abrahamson in testing those herbicides that will control weeds and not effect seedlings. The effort has produced outstanding results; we have 90% of our tree species under chemical-weed control. The program is still on-going for those newly acquired species. Regularly when the seedlings are 4-6 inches in height, we will use a mechanical brush hoe to control weeds in seedbeds. Not only are weeds controlled, but an additional benefit is the break-up of the soil crust in the seedbed. Our last line of defence in the great weed wars are seasonal personnel, armed with hoes, weeding knives and/or round-up herbicide applicators. During the course of the summer our temporary crew numbers 5-7 people.

A comprehensive lateral root pruning and root wrenching schedule is followed to develop fibrous root systems of conifers and hardwoods for improved outplanting survival.

The seedling harvest season at this nursery begins late November/early December and ends mid- to late March. Winters in Oklahoma tend to be wet and cold with occassional snow. Usually in January we experience a two to three week freeze and all harvesting comes to a halt. After that time the ground thaws and harvesting resumes. In the past a Grayco Seedling Harvester was used to lift the seedlings; now we use exclusively Fobro lifters. All seedlings are processed and counted before shipment. The seedlings are graded as per accepted industry standards for height and caliper, grouped into 50's and machine-tied. A heeling-bed is used for temporary storage of hardwoods. The seedling cooler is used for storing remaining hardwoods and all conifers. The temperature of the cooler is 34 degrees and the relative humidity is 100%.

The majority of our tree sales are to small rural landowners; average order size is about 500 seedlings. Cooperators will receive their seedlings packages either through the United Parcel Service (UPS), or by picking them up at the nursery. Friday is the designated pick-up day and those that are included are notified a week in advance. This method of using UPS to ship seedlings and the one designated pick-up day/week is quite effective.

For the past two seasons, with the cooperation of the Soil Conservation Service and the State Conservation Commission we have located numerous seedling distribution sites in communities statewide. By distributing the seedlings directly to the landowners from our refrigerated seedling trucks, we hope for greater out-planting survival.

Annually Forestry Division service foresters will conduct comprehensive seedling survival investigations at numerous planting sites statewide. This information will be used to help evaluate the cultural practices used for producing seedlings at the nursery. We feel these survival studies are necessary for the continued production of quality seedlings. Service foresters also assist in seed location and collection. They develop and help implement planting plans for rural landowners. Our service foresters serve as a valuable extension of the Regeneration Center.

The Forestry Division manages a genetically improved southern pine seed orchard in southeast Oklahoma. We are utilizing the advancing front concept which involves the most productive families currently available. The initial orchards were established in the mid-60's and currently coming into full production. This provides the landowners of Oklahoma with the only available local source of genetically improved loblolly and shortleaf pine seedlings which have been thoroughly field tested through progeny tests to determine the most productive sources.

These seedlings will give higher yields of high quality timber in a shorter amount of time than "woods run" seedlings. The Division is a member of Western Gulf Forest Tree Improvement Program (WGFTIP). This is a cooperative whose members include other state and private organizations interested in the genetic improvement of forest trees. Currently 100% of all shortleaf and loblolly pine distributed by the Division is genetically improved. Through continued research and testing with WGFTIP and Oklahoma State University, the Oklahoma Forestry Division will continue to provide the very best planting material available to the landowners of Oklahoma.

Through proper soil management, timely and appropriate cultural practices and quality control, we are ensuring the continued production of quality tree and shrub seedlings for conservation plantings in Oklahoma.

Priming Treatments to Improve Pine Seed Vigor[1]

S. W. Hallgren[2]

Abstract.--Osmotic priming improved both final germination and rapidity of germination in loblolly pine and showed a detrimental effect or no effect on slash pine seeds. The beneficial effects of priming were lowest for stratified seeds and greatest at a low germination temperature.

INTRODUCTION

Nursery managers prefer to work with high-vigor seed lots that show rapid uniform germination and produce vigorous seedlings under a wide range of conditions. Seedling costs are lower because there are fewer culls and uniform stands of seedlings are easier to manage. Thus, there is a strong incentive to improve techniques for controlling and manipulating seed vigor.

Seed priming has shown promise as a technique for improving seed vigor in numerous agricultural and horticultural species (Heydecker and Coolbear 1977, Heydecker et al. 1973). The technique has been used to improve germination in cold soils (O'Sullivan and Bouw 1984, Sachs 1977), to alleviate thermodormancy (Valdes et al. 1985, Guedes and Cantliffe 1980) and to increase rate and uniformity of crop emergence (Heydecker and Coolbear 1977, Heydecker et al. 1973, Holley et al. 1984). Seeds are imbibed in an osmoticum that allows all the processes of germination to proceed to completion except radical emergence. The treatment is long enough to bring all the seeds to the same point, posied just before the last step in germination. Upon termination of the treatment, seeds are introduced to water and the germination process proceeds rapidly to completion (Bewley and Black 1985).

Previous work on priming required rather cumbersome techniques for bringing the seed in contact with the osmoticum that worked well for small quantities of seed (Heydecker and Coolbear 1977). Recently, a seed priming system was developed at Oklahoma State University that proved to be effective in priming vegetable seeds and could be upgraded to handle large quantities of seed. Basically, seeds are primed in columns of osmoticum that are vigorously aerated to insure adequate gas exchange for the seeds (Akers and Holley 1986, Akers et al. 1984, Holley et al. 1984).

This system was tested with loblolly (Pinus taeda L.) and slash pine (Pinus elliottii Engelm.) seed and the results were promising. Some of the preliminary results are presented here. A more complete evaluation of the technique is being prepared for publication in a scientific journal.

MATERIALS AND METHODS

Seeds used in the study were from single bulk lots of improved loblolly pine and slash pine collected in 1985 and supplied by the Texas Forest Service. Prior to priming the seeds were divided into two equal groups, one to remain in cold storage and one to receive a cold moist stratification treatment for 53 days.

The seeds were primed in transparent columns of vigorously aerated priming solution at 25°C (Akers and Holley 1986). The solutions were prepared from polyethylene glycol, molecular weight 8000, and water to have a water potential of -1.0 MPa. Each column contained 300 ml of solution and 400 seeds. Solutions were changed daily at first and every other day later in the 11 day treatment period. Light was not excluded from the priming columns. One

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group of seeds was not primed and was given an additional 11 days of stratification for a total of 64 days.

Following 11 days of priming the seeds were washed and divided into groups to be placed in two germinators, one at constant 25°C and another at 15°C. At 25°C the temperature is near optimum for germination of the southern pines and 15°C is considered stressful (Association of Official Seed Analysts 1981, Dunlap and Barnett 1984). The seeds received natural lighting during germination. The seeds were arranged in 4 replicates of 50 seeds on moist filter paper and the layout was a randomized complete block design in each incubator.

Germination was counted for 37 days, everyday at first and less frequently as germination slowed. A seed was considered germinated when the growing radical began to show geotropic curvature (Dunlap and Barnett 1984). Analysis of variance and the Least Significant Difference were used to determine the significance of treatment effects on final percent germination and the number of days to reach 50 percent of the final total germination (Steel and Torrie 1980).

RESULTS

The effect of priming on final germination for loblolly pine at 25°C was an increase of nearly 50 percent for unstratified seeds and no change for stratified seeds (Table 1). Days to 50 percent germination was reduced by more than 50 percent by priming for both stratified and unstratified seeds. Stratification alone increased final germination by 80 percent and reduced days to 50 percent germination by nearly 50 percent.

Table 1. Effects of priming on final percent germination and days to 50 percent germination for stratified and unstratified loblolly and slash pine seeds germinated at 25°C.

	Final Percent Germination		Days to 50% Germination	
	Stratified		Stratified	
	No	Yes	No	Yes
Loblolly Pine				
Not Primed	[1]53 b	96 *	8.6 a	4.6 a*
Primed	79 a	96 *	3.1 b	2.0 b
Slash Pine				
Not Primed	88 a	92 a	4.8	3.8
Primed	72 b	66 b	4.4	3.6

[1]For each species and stratification treatment means followed by the same letter are not different at the 5 percent level; * = stratification treatment significant at the 5 percent level.

In contrast, slash pine final germination at 25°C showed a reduction due to priming of 18 and 28 percent for unstratified and stratified seeds. Stratification alone had no effect on percent germination and neither stratification nor priming affected days to 50 percent germination.

At 15°C loblolly pine showed only 2 percent germination when unprimed and unstratified (Table 2). Final germination was increased by stratification to 89 percent and by priming to 35 percent, and priming had no effect on stratified seeds. Days to 50 percent germination for stratified seeds was reduced by 60 percent by priming.

Table 2. Effects of priming on final percent germination and days to 50 percent germination for stratified and unstratified loblolly and slash pine seeds germinated at 15°C.

	Final Percent Germination		Days to 50% Germination	
	Stratified		Stratified	
	No	Yes	No	Yes
Loblolly Pine				
Not Primed	[1]2 b	89 *	-	13.4 a
Primed	35 a	93 *	8.1	5.4 b
Slash Pine				
Not Primed	40	88 a*	13.2	11.3
Primed	35	44 b	12.4	13.4

[1]For each species and stratification treatment means followed by the same letter are not different at the 5 percent level; * = stratification treatment significant at the 5 percent level.

The effect of priming on percent germination for slash pine at 15°C was nil for unstratified seed and a 50 percent reduction for stratified seeds. Stratification alone more than doubled percent germination. Days to 50 percent germination was unaffected by both priming and stratification.

DISCUSSION

The results of this study demonstrated that osmotic priming improves the vigor of loblolly pine seeds (Table 1 and 2). Osmotic priming is known to have beneficial effect on

the vigor of seeds of many agricultural crops (Heydecker and Coolbear 1977). There has been very little work done with tree seeds.

Osmotic priming, like stratification, can improve both final germination and rapidity of germination. The beneficial effects of priming are less if the seeds are stratified before priming, indicating that both treatments may affect some of the same germination processes.

The beneficial effects of priming for loblolly pine were even greater at a low germination temperature than at a nearly optimum temperature (Table 2). These results are consistent with findings for agricultural crops that priming can improve germination at suboptimum temperatures (O'Sullivan and Bouw 1984 and Sachs 1977). Apparently loblolly pine seeds are especially sensitive to low temperature stress during germination (Dunlap and Barnett 1984) and osmotic priming can be a practical option for overcoming the sluggish germination at low temperatures.

The results presented here are inconsistent with the previous findings that osmotic priming improved germination of slash pine seeds (Haridi 1985). The two studies are not entirely comparable since different techniques were employed and the priming treatment ran for nearly twice as long in the current study as in the prior one. There were many ways the techniques used in the current study could be adjusted to meet the needs of different species including changes in temperature, solution concentration, oxygen levels, types of osmoticum and length of treatment.

It is well known that loblolly pine and slash pine have different stratification requirements for removal of dormancy and it is not surprising that they show different responses to the same osmotic priming treatment (Krugman and Jenkinson 1974).

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Effects of Nursery Density on Shortleaf Pine[1]

John C. Brissette and William C. Carlson[2]

Abstract.--A technique to determine the effective nursery bed density of individual seedlings was developed and then used to evaluate density influence on shortleaf pine (*Pinus echinata* Mill.) bare-root seedlings. At lifting, mean height had increased while mean root collar diameter and root volume had decreased with increasing effective density. After the first growing season, seedlings produced at lower effective densities exhibited greater height and diameter growth than seedlings grown at higher effective densities.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most important species used for artificial regeneration on the Ouachita and Ozark National Forests (Kitchens 1987). Approximately 12 million seedlings are planted annually on about 7,000 hectares of the two forests. Although artificial regeneration of shortleaf pine represents a large investment on the two forests, success of the program has been limited by poor seedling survival and growth. Excluding the severe drought year of 1980, seedling survival has averaged about 50 percent since large-scale planting was begun in the 1970's. The reasons for poor seedling performance are not clear. The planting sites are harsh, the soils are rocky, and the south and west aspects are exposed to hot, droughty conditions throughout the summer. However, many forest managers do not think that difficult site conditions alone explain the poor seedling performance. They note that seedling quality also must be considered. Consistent production of quality planting stock requires a thorough knowledge of seedling development in the nursery and an understanding of how nursery culture impacts field performance.

In a recent review, Barnett and others (1987) found few references to shortleaf pine stock quality. Two of the most enlightening items were by Chapman (1948) and Clark and Phares (1961). The earlier paper dealt with the effects of morphological characteristics on the survival and initial growth of seedlings planted on old field sites in Arkansas, Missouri, Indiana, and Ohio. The later paper dealt with survival and growth of the plantations in Missouri and Indiana at age 19 and 20. In general, larger diameter seedlings performed better initially, and that early superiority was maintained over time.

One of the most critical factors determining seedling quality is seedbed density. Density is a measure of competition among seedlings for growing space and relates to their ability to receive light, water, and nutrients. As density increases, yield of cull seedlings increases and average root collar diameter decreases (Shoulders 1961). Seedling weight also decreases with increasing density. In loblolly pine (*P. taeda* L.), root weight is reduced proportionately more than shoot weight, resulting in a corresponding decrease in root-to-shoot ratio (Harms and Langdon 1977). Mexal (1981) concluded that the biological optimum density for growing loblolly pine seedlings is $200/m^2$.

With the mechanical sowing methods in use, and less than perfect germination, nursery bed density is seldom uniform. Although bed density is a useful criterion for evaluating average seedling characteristics on a plot basis, bed density consequence on individual seedlings is difficult to determine.

In 1985 a study was established at Weyerhaeuser Company's Magnolia Forest Regeneration Center in southwest Arkansas to address the quality of shortleaf pine planting stock used to reforest Ouachita and Ozark Mountain sites. The effects of nursery bed density and fertilization on the morphology, nutrient status, and root growth potential of seedlings from that

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study were reported previously (Brissette and Carlson 1987). Objectives of this paper are to describe a method of determining the effective density of individual seedlings and to compare the morphology and subsequent first-year field performance of seedlings grown at a range of effective densities.

MATERIALS AND METHODS

This study was part of one designed to evaluate nitrogen (N) and phosphorus (P) fertilization as well as seedbed density. The design and installation of the experiment were described in a previous paper (Brissette and Carlson 1987), and will be only briefly reviewed here. There were two levels of P, five levels of density, and four levels of N applied in a split-split plot design with four replications. The levels of P were the level in the soil before the experiment and enough 0-300-0 fertilizer incorporated prior to seedbed formation to theoretically raise the level 150 percent. No significant effects were attributed to the P treatments (Brissette and Carlson 1987).

Ammonium sulphate was applied in five biweekly topdressings at levels ranging between 55kg N/ha and 170kg N/ha. The effect of N on morphological attributes peaked at an intermediate level, and interacted with mean seedbed density in its effect on root growth potential (Brissette and Carlson 1987).

The study was sown on April 16, 1985, with Weyerhaeuser-designed precision vacuum equipment that sowed eight double rows of seeds. The five target densities of living seedlings were: (1) $160/m^2$, (2) $230/m^2$, (3) $295/m^2$, (4) $360/m^2$, and (5) $430/m^2$.

Actual average seedbed densities were lower than the target densities because germination was poorer than expected. Average density for each level in the study was: $141/m^2$, $218/m^2$, $269/m^2$, $296/m^2$, and $296/m^2$, Note that the two highest levels were the same. Although the highest density was well below the sowing target, it was higher than the operational level ($270/m^2$) recommended by Chapman (1948) but much lower than the density ($540-590/m^2$) suggested as a maximum by Wakeley (1954).

Early in the study a transect was taken across the center of each plot and one seedling from each double drill row was permanently tagged as a measurement tree. Thus, 1280 identified seedlings were followed throughout the study. Those seedlings are the basis for this paper.

To determine effective density we reasoned that seedling shoots are most affected by other seedlings that are closer than about 15 cm. Root competition probably occurs at greater distances, but we assumed that most water and nutrient uptake is also within 15 cm. Thus, seedlings sown in conventional drills on 15 cm spacing compete within their own drill row and with seedlings in adjacent drill rows. To determine the effective density of each of the labeled seedlings the number of seedlings in the double drill row for 15 cm on either side was added to the similar number obtained on adjacent drill rows. The total is an estimate of the number of seedlings with which the measurement tree was competing.

Because competition is usually expressed as the number of seedlings per unit area, the number of competing seedlings was converted to number per square meter, i.e., the effective density for each measurement tree. The conversion was based on the area included in obtaining the number of competing seedlings. The measurement area was 30 cm long, the nursery beds were 1.2 m wide with eight drill rows. Since the seedlings from the six interior drill rows are competing with those on either side (three rows total) the area was calculated to be $3/8 \times 1.2 \text{ m} \times 0.3 \text{ m} = 0.135 \text{ m}^2$. The effective density was then calculated as the number of competing seedlings/0.135 m^2--for example, 36 seedlings/0.135 m^2 = 267 seedlings/m^2. Because the seedlings on the outside of the nursery bed only have one adjacent drill row (two competing rows) their area of competition was calculated to be $1/4 \times 1.2 \text{ m} \times 0.3 \text{ m} = 0.09 \text{ m}^2$. Thus for a seedling on the outside drill row competing with 19 additional seedlings, its effective density is 20 seedlings/0.09 m^2 = 222 seedlings/m^2.

Each of the 1280 measurement seedlings was labeled with an aluminum tag attached to the stem with a wire. When the beds were laterally root pruned prior to lifting the tags and wires caused extensive stem damage. When the seedlings were hand-lifted on January 20-21, 1986, 970 of the original 1280, were undamaged. These undamaged were measured for root collar diameter, height (shoot length), and root volume, using the displacement method (Burdett 1979). The seedlings were kept in cold storage between lifting and planting except when they were being measured. The measurements were made in a laboratory and required less than 5 min per seedling.

On February 7, 1986, the seedlings were machine-planted on a sod-covered site at the J. K. Johnson Tract of the Palustris Experimental Forest west of Alexandria, LA. On March 5-6, 1987, the total height and ground line diameter of all living trees were measured. Relative growth rates (RGR) were calculated as percent change in height and diameter between the nursery and first-year field measurements (field measurement-nursery measurement/nursery measurement X 100).

Seedling morphology and first-year field performance data were analysed by regression techniques. The 970 trees were subdivided in 10 density classes of 97 observations each and the means were used in the analyses.

RESULTS AND DISCUSSION

The effective densities for the 970 seedlings ranged from 55 to 431 seedlings/m^2 with a mean of 246/m^2 and a coefficient of variation (CV) of 30 percent. When divided into 10 subclasses of 97 seedlings each, the mean densities ranged from 123 to 365/m^2 (table 1). The amount of N available per seedling was computed by dividing the total N applied by the effective density. It ranged from 13 to 260 mg/seedling with a mean of 47 mg/seedling. Within the density classes, mean N ranged from 30 to 87 mg/seedling (table 1).

With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant ($p<.001$). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively. field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

Nursery bed density clearly had affected seedling morphology at time of lifting (table 1).

Table 1.--Nursery bed density effects on shortleaf pine seedling morphology and first-year field performance

Density class	Mean density	Mean N [a]	Nursery Ht	Nursery Dia	Nursery RV [b]	First-year field Ht	First-year field Dia	Relative growth Ht	Relative growth Dia
	--/m^2--	-mg/tree-	--mm--		--cc--	-------mm-------		-------%-------	
1	123	87	163	4.8	4.1	357	6.8	124	42
2	155	65	167	4.7	3.9	373	6.8	130	47
3	188	59	181	4.7	3.5	356	6.5	100	41
4	217	46	182	4.6	3.3	353	6.2	100	36
5	237	43	183	4.6	3.2	356	6.1	100	36
6	261	39	181	4.4	2.8	348	5.9	94	38
7	282	38	182	4.4	2.7	328	5.8	86	37
8	303	33	183	4.3	2.7	328	5.8	82	38
9	331	32	187	4.3	2.6	335	5.7	83	35
10	365	30	190	4.3	2.5	328	5.6	76	32
r^2 [c]		.98	.78	.92	.98	.75	.97	.88	.68

[a] N = nitrogen

[b] RV = root volume

[c] r^2 = coefficient of determination with mean effective density as the independent variable, see text for individual regression equations

Determination of nutrient uptake in fertilizer experiments requires destructive sampling. For this study concentrations of N, P, and K in seedling shoots were reported previously (Brissette and Carlson 1987). Although a theoretical amount of N was calculated for each seedling on the basis of effective density, it cannot be confirmed. Therefore, this paper's discussion is confined to the effects of density. Differences due to the four N rates applied are taken into account by analyzing the means of the density classes that are made up of approximately equal numbers from each N treatment. As shown in table 1, the average amount of N available per seedling decreases as density increases. Thus the effects of density on an individual seedling cannot be totally separated from the effects of N. This relationship should be kept in mind during the following discussion about morphology and field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

As mean density increased, mean height increased while mean diameter and root volume decreased. With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant ($p<.001$). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively.

Nursery managers seldom have a seedlot or even a species growing at the range of densities represented in this study. For pines, managers are most interested in densities between 215 and 325/m^2. To evaluate this range in more detail, we selected two of our density classes and compared them with analysis of variance (ANOVA). The classes selected from table 1 were 4 and 8. Class 4 had a mean density of 217/m^2. It had a relatively narrow range of densities of from 204 to 226/m^2. Class 4 is the one just above the biological optimum density recommended for loblolly pine by Mexal (1981). At most nurseries

it would be considered low density. Class 8 had a mean density of $303/m^2$ and a range (between 292 and $316/m^2$) nearly as narrow as Class 4. Class 8 would be considered moderately high density.

Seedlings from Classes 4 and 8 did not differ significantly in height (MSE=1521, p =.905). Although the difference in mean diameters was only 0.3 mm, it was significant (MSE=0.96, p = .020). The 0.6 cc difference in root volume was also significant (MSE=1.33, p< .001).

Nursery managers often evaluate their crop quality as the percentage of seedlings that exceeds some minimum standard. For the southern pines, morphological seedling grades were developed by Wakeley (1954), drawing on several years of research results and operational observations. These grades are still recognized as the standard measure of southern pine seedling quality. Three grades are defined, two plantable and one cull, based primarily on root collar diameters of undamaged seedlings. For shortleaf pine the minimum diameter for plantable seedlings (Grade 2) is 3.2 mm while the minimum for premimum seedlings (Grade 1) is 4.8 mm. In our density Class 4, only 3 percent of the seedlings were less than 3.2 mm and would have been considered culls, while in Class 8, 12 percent were culls. In Class 4, 40 percent of the seedlings were Grade 1, while in Class 8, 30 percent were Grade 1.

Root volume is seldom evaluated operationally but is considered one of the most important morphological characteristics. During the period between planting and elongation of new roots, root volume largely determines the level of plant moisture stress that can develop (Carlson 1986). Larger root volumes also provide more sites for new root growth, thus root volume has been positively related to root growth potential in both loblolly pine (Carlson 1986) and shortleaf pine (Brissette and Carlson 1987). For these reasons large root volumes are especially important when seedlings are planted on droughty sites. However, root volume is extremely sensitive to nursery bed density. Across our 10 density classes, root volume decreased sharply as density increased (fig. 1).

First-year field survival was excellent, being 98 percent overall. Among seedbed density classes, first-year survival was between 96 and 99 percent. Field growth was statistically related to nursery bed density (table 1). The regression between first-year field height and seedbed density was significant ($p<.005$, $r^2 = 0.75$). But, unlike nursery height, field height decreased as the density at which the seedlings were grown increased (fig. 2). That is, the shortest trees from the nursery were the tallest in the field after the first growing season. First-year field diameter was also significantly related to nursery density ($p< .001$, $r^2 = 0.97$). Like nursery diameter field diameter decreased with increasing seedbed density (fig. 3).

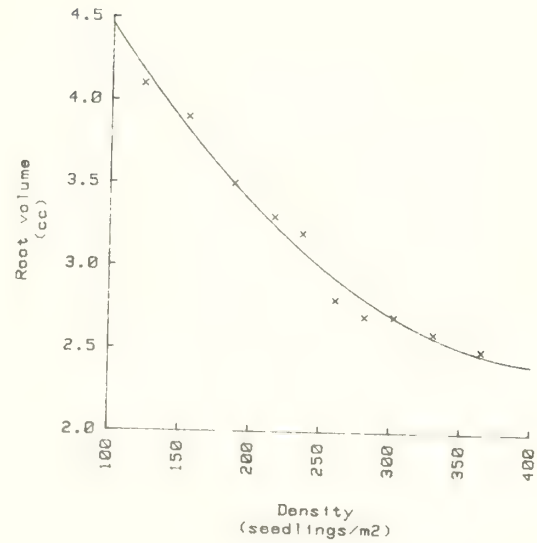

Figure 1.--Relationship between mean effective density and mean root volume of shortleaf pine seedlings, n=97.

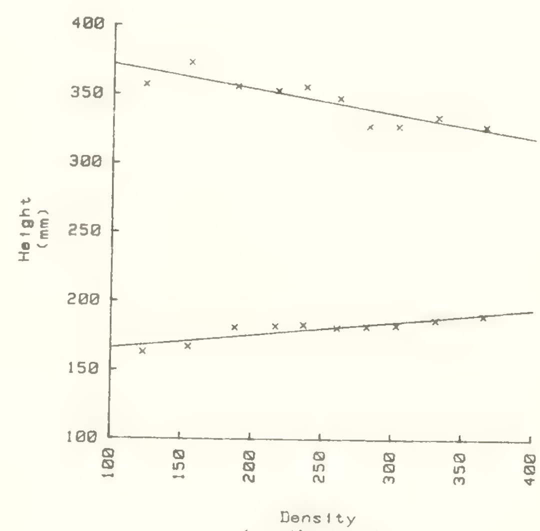

Figure 2.--Relationship between mean effective density and mean shortleaf pine seedling height at lifting (lower curve, n=97) and after one year in the field (upper curve, n=93-96.

In terms of RGR, changes in heights and diameters between the nursery and the field were also related to nursery density (table 1). For

the 970 trees, the mean RGR for height in the field was 97 percent; 100 percent represents a doubling in size. When regressed with seedbed density the relationship was significant ($p<.001$, $r^2 - 0.88$). Diameter RGR was not nearly as great with an overall mean of 38 percent, but was also significantly realted to nursery density ($p< .005$, $r^2 - 0.68$). For both height and diameter, RGR in the field declined with increasing nursery density (fig. 4).

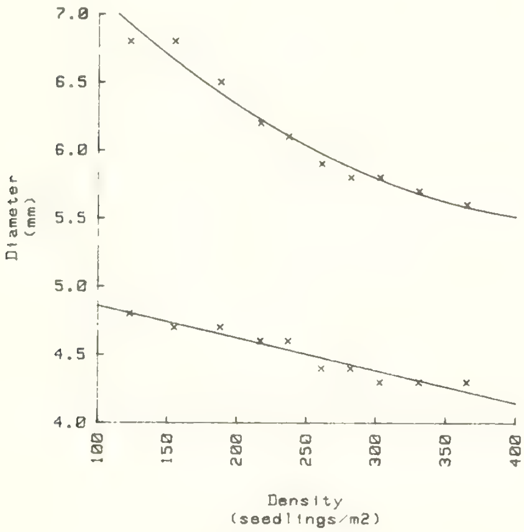

Figure 3.--Relationship between mean effective density and mean shortleaf pine seedling root collar diameter at lifting (lower curve, n=97 and ground line diameter after one growing season (upper curve, n=93-96).

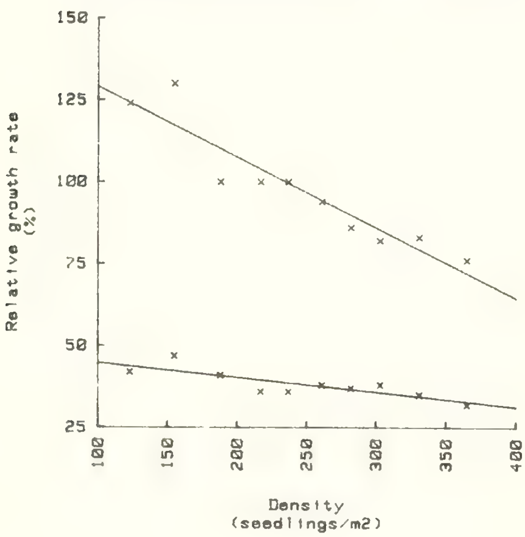

Figure 4.--Relationship between mean effective density and mean relatilve first-year growth rates (field measurement-nursery measurement/nursery measurement X 100) for seedling height (upper curve, n=93-96) and diameter (lower curve, n=93-96).

Both nursery managers and foresters benefit when they agree on a set of specifications for a target seedling that will give the desired performance on a particular planting site. Target seedling specifications differ somewhat from seedling grades because targets are based on performance goals. Thus target specifications are often more stringent than morphological grades, which are usually based on a minimum performance level. One proposed goal for southern pines is a doubling in height during the first growing season in the field (Brissette 1985). Data from this study can be used to help specify a target seedling that will meet that goal. The regression equation for relative height growth in terms of nursery density (X = seedlings/m^2) is:

$$\text{RGR HT} = 150.5 - 0.21537X,\ r^2 = 0.88$$

To achieve a doubling in height (100 percent change), the equation predicts a density of 235/m^2. The equations for nursery height (HT), diameter (DIA), and root volume (RV), in relation to density are:

$$\text{HT} = 156.2 + 0.09608X,\ r^2 = 0.78$$

$$\text{DIA} = 5.1 - 0.00237X,\ r^2 = 0.92$$

$$\text{RV} = 5.9 - 0.01648X + 0.00002X^2,\ r^2 = 0.98$$

These equations predict that a seedling capable of doubling in height under the conditions of this study: (a) is no more than 179 mm tall (minimum mean height in the data set was 163 mm), (b) is at least 4.5 mm in root collar diameter, and (c) has a root volume of at least 3.1 cc. These specifications could also be estimated graphically from figures 1-4.

These specifications are based on seedlings grown on a less droughty site than those typically found in the mountains. However, the height suggested by the analysis is at the low end and the diameter is at the high end of the range of specifications given for an initial target seedling to be planted on Ouachita and Ozark Mountain sites (Barnett and others 1987). Therefore, we think that the root volume suggested by this analysis is an appropriate addition to those target specifications. Note that 3.1 cc is the target root volume, the minimum acceptable would be somewhat less and would depend on what was defined as a minimum performance level.

SUMMARY AND RECOMMENDATIONS

This study was designed to evaluate the effect of nursery bed density on the morphology and subsequent field performance of shortleaf pine seedlings. Because seedling morphology is so strongly related to seedbed density, it was not possible to separate the effects of density and morphology on field performance in this study. However, based on the above results and discussion the following recommendations are made:

1) To produce shortleaf pine seedlings with the morphological characteristics for rapid first-year growth in the field, nursery bed density should be kept below 235/m^2.

2) For any species, root volume should be included in the development of target seedling specifications. While not as easy to measure as shoot length or diameter, root volume determination is not excessively difficult nor time consuming.

3) Because density can influence seedling nutrient status, it should be remembered that the effects of density on growth and performance are confounded by the effects of fertilization.

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Polymeric Nursery Bed Stabilization to Reduce Seed Losses in Forest Nurseries[1]

William C. Carlson, John G. Anthony, and R. P. Plyler[2]

Abstract: A polymerization treatment using Geotech, a copolymer of acrylate and vinyl acetate monomers, was used to stabilize forest nursery beds to substantially reduce wind and water erosion. Such treatment did not affect either the temperature of the seed zone in the soil or germinant emergence. Seed losses were reduced by the treatment, resulting in increased nursery yield.

[1] This article appeared in full in the Southern Journal of Applied Forestry, 11(2):116-119, 1987.

[2] William C. Carlson and John G. Anthony are with the Southern Forestry Research Center, Weyerhaeuser Company, Hot Springs, Arkansas. R. P. Plyler is with Weyerhaeuser Company's Magnolia Forest Regeneration Center, Magnolia, Arkansas.

Improving Outplanting Survival of Stored Southern Pine Seedlings by Addition of Benomyl to the Packing Medium[1]

James P. Barnett and John C. Brissette[2]

Abstract.-- Field survival of longleaf, shortleaf, slash, and loblolly pine seedlings planted with benomyl incorporated in the packing medium was markedly improved over that of controls with clay-slurry packing medium. Longleaf pine (*Pinus palustris* Mill.) and shortleaf pine (*P. elliottii* Englem.) seedlings, which are more difficult to store, had greater magnitudes of response than the more easily stored loblolly and slash pine seedlings.

INTRODUCTION

Clay-benomyl (Benlate®)[3] mixture used as a root dip treatment at the time of planting provides systemic protection of longleaf pine (*Pinus palustris* Mill.) seedlings from brown-spot disease (*Scirrhia acicola* (Dearn.) Siggers). Protection should last for at least one year in the field (Kais and Barnett 1984; Cordell et al. 1984; Kais et al. 1986a, 1986b). This treatment has resulted in improved survival and early height growth (Kais 1985; Kais and Barnett 1984; Kais et al. 1986b). Benomyl is a very effective fungicide that is recommended for a number of other uses in container and bare-root nursery seedling production (Barnett and Brissette 1986; Sutherland 1984). It also has the advantage of having no phytotoxic effect on mycorrhizal development; in fact, seedling development is enhanced by benomyl use (Pawuk and Barnett 1981).

Recent tests have shown that longleaf pine seedling storage may be dramatically improved by the incorporation of benomyl into the clay slurry used for seedling packing (Barnett and Kais 1987). Early results have stimulated additional testing and extension of the technique to other species.

METHODS

Three studies are underway by the Southern Forest Experiment Station to evaluate the effect of fungicides on storage of southern pine seedlings. In study 1, longleaf pine seedlings from a single seed lot were lifted in January 1985 from beds at the Ashe Nursery in Mississippi. Seedlings were divided into two sublots for two storage periods (1 and 3 weeks), and five root packing material treatments were applied for each storage period: (1) clay slurry control, (2) clay slurry, with a benomyl dip added at the time of planting, (3) clay slurry with benomyl added at the time of packing, (4) peat moss control, and (5) peat moss combined with a benomyl dip treatment. Benomyl was applied as a 10-percent mixture of Benlate® WP50 with kaolinate clay. This resulted in an approximate 5-percent a.i. of benomyl in the clay slurry or dip. A 10-percent dilution of benomyl in water was used as a dip prior to packing with peat moss for treatment 5.

In study 2, longleaf pine, loblolly pine (*P. taeda L.*), and shortleaf pine (*P. echinata* Mill.) seedlings from the Ashe Nursery were lifted in January 1986 and divided into three sublots for three storage periods (0, 3, and 6 weeks). Two root packing treatments were applied to each of the three sublots: (1) clay slurry control and (2) 10-percent Benlate® WP50 and clay slurry mixture.

In study 3, two seedlots (Florida and Mississippi) of slash pine (*P. elliotti* Engelm.) and three (Alabama, Louisiana, and north Mississippi) of loblolly pine were lifted at the Ashe Nursery late in the season (March 9, 1987) and subdivided for two treatments (0 and 6 weeks) The dosage rate was reduced to one-fourth the rate of the earlier test, i.e., a 2.5-percent mixture of Benlate® WP50 and kaolinate clay. The control was a clay slurry.

[1]Paper presented at the Intermountain Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

[2]Principal silviculturist and silviculturist, respectively, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

[3]Mention of trade names is for information only and does not constitute endorsement by the USDA Forest Service.

In all tests, seedlings were packed in Kraft polyethylene bags (350 per bag) and stored at 35°F. Seedlings of the 0 week treatment were planted within 3 or 4 days, while the other plantings were made after 3 or 6 weeks of storage. Seedlings were machine planted at 5- by 5-foot spacings in 2 rows of 50 seedlings; there were 4 replications. Study 1 was outplanted on two different sites in central Louisiana. Only one site was used for the other two studies. Seedling survival was measured in June and December of the same year following planting. Study 1 was also measured for survival and height after 2 years in the field.

Differences in survival were tested for significance at the 0.05 level by analyses of variance. Duncan's Multiple Range Test was used to evaluate treatment means.

RESULTS

Study 1.--The outplanting site had a considerable influence on longleaf pine seedling survival after two growing seasons. Heavier grass and woody competition as well as greater brown-spot incidence occurred on site 1. Nevertheless, treatment effects followed the same trends on both sites. Both length of seedling storage and packing-medium treatments significantly affected seedling performance. Survival of seedlings that had undergone 3 weeks of storage was markedly lower than for the 1-week storage period (fig. 1). The effect of storage varied greatly depending on packing-medium treatments, and for both sites there was a storage X packing treatment interaction.

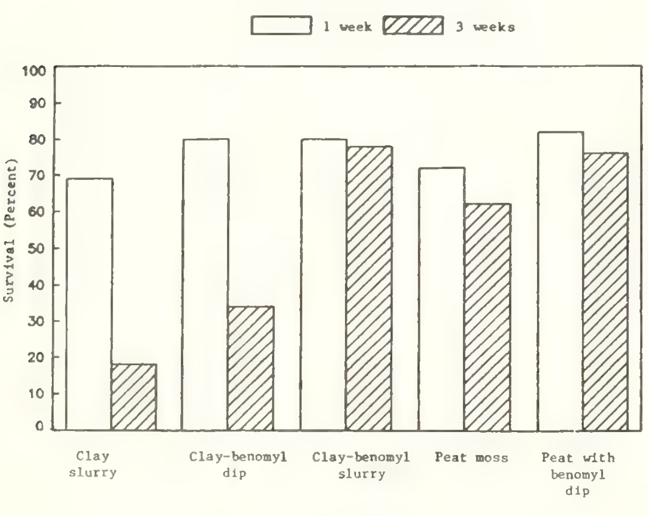

Figure 1.--Survival of longleaf pine seedlings stored 1 and 3 weeks with various root packings 2 years after outplanting (Study 1.)

The clay-slurry and peat moss controls had consistently lower survival than any of the benomyl treatments when stored 1 week (fig. 1). The magnitude of treatment difference was much greater for the 3-week storage treatment. The clay-slurry treatments averaged 19, 33, and 79 percent survival for the control, benomyl dip at planting, and the clay-benomyl slurry, respectively. The peat moss control averaged 64 percent, three times that of the clay-slurry control. The addition of benomyl to the peat moss treatment improved survival by 13 percentage points.

Study 2.--Longleaf, loblolly, and shortleaf pine seedlings receiving clay-slurry control and clay-benomyl treatments were planted after storage periods of 0, 3, and 6 weeks. Response after 1 year varied by species. Longleaf pine seedlings had the lowest survival regardless of treatment, and benomyl improved survival after all lengths of storage (fig. 2). In contrast, survival of loblolly pine seedlings was almost 100 percent regardless of treatment or storage. Survival of shortleaf pine seedlings without storage (0-week storage period) averaged 99 percent, but after being stored for 3 and 6 weeks, survival of the controls dropped to 83 and 36 percent, respectively. Benomyl-treated shortleaf seedlings maintained the same level of survival even after storage (fig. 2).

Study 3.--The loblolly and slash pine seedlings lifted later in the season (March 9) were planted within 1 week (0-week storage period) and after 6 weeks. These seedlings were treated with the clay slurry and a clay-benomyl slurry at one-fourth the rate used in the slurries of the other studies. After 3 months in the field, there were marked differences between packing treatments. Loblolly pines stored 6 weeks averaged 23 and 87 percent, respectively, for the clay and clay-benomyl treatments (fig. 3). Comparative treatments for slash pine averaged 9- and 88-percent survival.

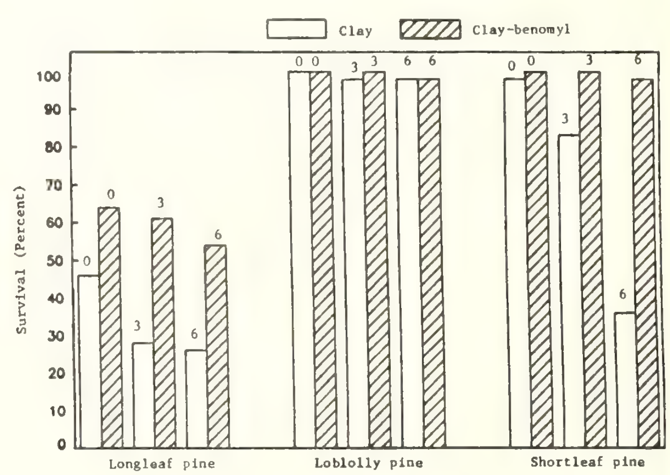

Figure 2.--Survival of longleaf, loblolly, and shortleaf pine seedlings stored for 0, 3, and 6 weeks with two root packings 1 year after outplanting (Study 2). Numerals above bars represent number of weeks stored.

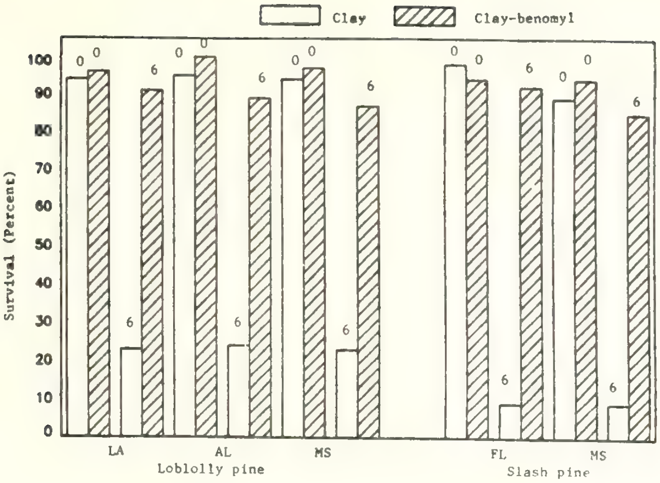

Figure 3.--Survival of loblolly and slash pine seedlings stored for 0 and 6 weeks with two root packings 3 months after outplanting (Study 3). Numerals above bars represent number of weeks stored.

DISCUSSION

Results of all three tests showed a very positive response from the incorporation of benomyl into the clay slurry used for seedling packing. The root dip in benomyl followed by seedling storage in peat moss followed the same trend. Preliminary pathological evaluations indicate that benomyl is controlling pathogenic microorganisms that reduce seedling quality after storage of 3 or 6 weeks. Survival of longleaf pine seedlings, which are the most difficult of the southern pines to store, is improved by benomyl treatment even when the seedlings are outplanted within 1 week. The second greatest response was with shortleaf pine. Major improvements in shortleaf pine survival occurred with 3 to 6 weeks of storage.

Loblolly pine seedlings lifted in early January survived well without benomyl treatment. However, when loblolly and slash seedlings were lifted in March and stored for 6 weeks, seedlings that received benomyl treatment were able to be stored satisfactorily. Those without such treatment showed a large decrease in survival. Additional studies are underway to evaluate the mechanisms involved in deterioration of seedlings during storage; other studies are underway to determine the effect of date of lifting on seedling storage.

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Measuring Tree Seed Moisture Content Now and in the Future

Robert P. Karrfalt[1]

Abstract.-- The procedure used in developing conversion charts for tree seed for use with a relatively inexpensive electronic seed moisture tester is given. A list of the species for which charts have been made is given. A brief discussion is presented on the potential future uses of regulating seed moisture.

INTRODUCTION

The regulation of seed moisture is critical to the management of high quality seed. Mechanical injury or high temperatures can have detrimental effects to be sure, but the moisture content of seeds no doubt is the most influential of all the factors that can effect the quality of seeds (Justice and Bass, 1979). The date of harvest of cones, fruits, or seeds is generally related to moisture content. Conifer cones must be air dried to a specified range of moisture content in order to produce maximum yields and highest quality seed. Kiln drying of cones that are too high in moisture content will result in case hardening of the cone and a poor seed yield. Most temperate zone species that have moisture contents below 10 percent can be stored at cold temperature for years while seed at high moisture content will live only a few months even with ideal temperatures. These are but a few brief examples of how critical the regulation of seed moisture is to the quality of seed.

ROUTINE SEED STORAGE

For routine seed storage the seed handler is concerned with maintaining seed basically at a threshold moisture level. For the vast majority of temperate species this threshold value is 10% on a wet weight basis. Extremely low values of 2 or 3% might lead to seed damage according to some reports, but data (Justice and Bass, 1979, Benson, 1970) exists that shows that this is probably not the case. The examples of loss of viability due to low moisture content are probably explainable as imbibitional injury when planted. A slow uptake of water would allow those seeds with ultra low moisture contents to maintain a high level of viability.

[1]Director, National Tree Seed Laboratory, USDA Forest Service, Dry Branch, Georgia.

A desirable test for moisture is one that is fast, inexpensive, and gives acceptable accuracy. There are a number of electronic moisture testers available that will give quick results. However, they generally cost about $1,000 or more. For the small forestry operation this might represent a substantial portion of the annual budget for equipment. So for many the $1000 meter may not be inexpensive. Also none of the meter manufacturers concern themselves with forestry and conservation seeds in the calibration of their meters. Therefore, the meter will not be useable until someone conducts the necessary measurements to relate meter readings to actual seed moisture contents.

For many years a small meter was available for which the National Tree Seed Laboratory had developed conversion charts. This was the PB-71 made by the Eaton Corporation. It was marketed under a number of names: Dole, Radson, Burrows, and Gilmore-Tatge. Unfortunately this meter was improved for the tester of grains, and tree and shrub seed testers could no longer use it. The electronic parts were modified such that they no longer functioned in the range needed for woody plant seed. To quickly replace this much needed meter, an effort was made in cooperation between the National Tree Seed Laboratory and many private and public agencies to develop conversion charts for another relatively inexpensive meter, the Dickey-john[1] grain moisture tester for corn. The following have donated seed for this work: R. W. McPhearson, California Division of Forestry, Michigan Department of Natural Resources, Dean Swift Seed Company, Louisiana Forest Seed Company W.W. Ashe Nursery, J. Herbert Stone Nursery, J.W. Toumey Nursery. The effort to develop charts is still going on, and the NTSL will be happy to develop a chart as soon as possible if your desired species are not on the charts.

[1]Use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

DEVELOPMENT OF THE CONVERSION CHARTS

The procedure followed in developing the moisture charts for the Dickey-john meter was based on the following reasoning. 1. The variation in meter readings among samples from the same seed lot and among seed lots at any given moisture content would be small (less than one percent moisture). If variation was large then the meter would not be useful because multiple readings would be required, and the meter would not be a quick test. 2. It follows from the first statement that the samples tested in the meter could all come from one seed lot if that seed lot was at all representative. 3. The concern in storing tree seed is that the moisture content be below a given threshold value. Therefore, whether the true moisture is 5, 6 or 8% is not important. What is important is that we are certain that the value is below the critical threshold. Our primary concern in developing these charts was, therefore, not necessarily to have a high degree of precision but to have numbers that will tell us that we have our seed dry enough for long term storage.

The first step in developing the charts was the selection of a seed lot that was of good average germination and purity for the species. This seed lot was then soaked overnight in water to fully imbibe the seed. The water was drained off, and the seed was placed on the seed drier. As soon as the seed was surface dry, a reading was taken on the meter and in the drying oven. The drying oven moisture determination was done on duplicate 5 gram samples at 103°C ± 2°C for 17 hours ± 1 hour (International Seed Testing Association, 1985). Generally the moisture content was in the neighborhood of 20 to 25% on the first reading. Subsequent readings were taken every one to two hours depending on how fast the drying was taking place. Readings were taken until the seed reached moisture contents of 4 to 6%. In some cases the end moisture content achieved was only 7 or 8%. Some of the species tested had a conversion chart developed for the PB-71 meter. Readings from the PB-71 served as a check that the seed lot being used was representative of the species. The reasoning on that point was this. If the reading from the PB-71 was within tolerance with the oven reading, then there was confidence that the seed lot being used was representative. In all cases the readings were within tolerance so that the procedure of using one seed lot seems valid.

The second step was the regression of the meter readings on the moisture contents determined by the oven procedure. This regression produced a prediction equation for calulating the meter readings from oven measurements. Using oven measurement values from 6 to 18% in steps of 0.5% a set of meter readings was computed from the prediction equation. The computed values are the conversion chart values. The measurements made with the Dickey-john meter on several loblolly pine seed lots agree with the readings found by the oven, and show that the procedure is appropriate.

Conversion charts have been made for the following species:

WESTERN SPECIES

Abies concolor
Abies grandis
Abies magnifica
Calocedrus decurrens
Picea engelmannii
Picea sitchensis
Pinus contorta
Pinus coulteri
Pinus jefferyi
Pinus lambertiana
Pinus muricata
Pinus ponderosa
Pinus radiata
Pseudotsuga menziesii

NORTHERN SPECIES

Betula paperifera
Betula allegheniensis
Larix laricina
Picea abies
Picea glauca
Picea mariana
Pinus banksiana
Pinus resinosa
Pinus strobus
Thuja plicata
Tsuga canadensis
Crataegus phaenopyrum

SOUTHERN SPECIES

Pinus clausa
Pinus elliottii
Pinus palustris
Pinus taeda
Pinus virginiana

Persons needing the charts may obtain them from the National Tree Seed Laboratory, Rt. 1, Box 182B, Dry Branch, GA 31020.

REGULATION OF SEED MOISTURE CONTENT IN THE FUTURE

To this point we have talked about regulating seed moisture as a very basic technology. We wanted only to maintain our seed below a given threshold of moisture so that we could safely have long term storage of seed. This is an extremely important aspect of seed moisture that will stay with us for as long as we store seed in the manner we currently do.

During the last 10 years, however, the literature has had some articles on regulating moisture content of stratified seed that allows the nursery manager to store seed while either maintaining the benefits of stratification or even enhancing the benefits of stratification. Danielson and Tanaka (1978) found that by air drying stratified seed of Douglas fir and ponderosa pine that the seed could be stored for up to 9 months without reinstating dormancy or causing deterioration of the seed. Belcher (1982) confirmed the findings of Danielson and Tanaka with Douglas fir and found the same to be true for loblolly pine. De Matos Malavasi et. al. (1985) showed that seedlings produced from air dried Douglas fir seed were larger at age 5 days than seedlings from seed which were stratified only. Numerous studies on improving the vigor of seeds by priming with PEG have been reported in the literature. It seems quite likely that the improvement in vigor might come from an effect brought on by the PEG regulating the moisture content of the seed. It is also well established that the moisture content of the seed and its various constituent parts has a profound control over the condition of the cell membranes and the metabolic and chemical activities that occur within the seed (Priestly, 1986).

In the future it is very likely that seed handlers will want to regulate the seed moisture for purposes of regulating the effects of the presowing treatments. Today's forms of stratification could well be replaced with more sophisticated procedures. To do this we will want to measure moisture in ranges between 20% and 30% or 40%. A type of meter like the Dickey-john will allow for quick measurements in this range. . Therefore, as the seed physiologists discover the critical moisture contents to regulate seed performance, the technology exists to adapt this new information for practical application by the nursery manager.

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Forest Tree Nursery Herbicide Studies at the Oklahoma Forest Regeneration Center[1]

Lawrence P. Abrahamson[2]

Abstract.--Eight herbicides (registered for similar uses in the U.S.) were extensively evaluated at the Forest Regeneration Center, Oklahoma Forestry Division, Washington, Oklahoma, for weed control on first year seedling nursery beds. Phytotoxicity evaluations of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin and prometryn on 19 different conifer and hardwood species are presented.

Additional key words: Enide®, Treflan®, Dacthal®, Caparol®, Devrinol®, Modown®, Goal®, and Ronstar®.

INTRODUCTION

The USDA Forest Service developed a number of nursery herbicide projects in the United States out of a recognition of the potential benefits of herbicidal control of weeds in nursery seedbeds. This paper will concentrate on projects conducted at the Forest Regeneration Center, Oklahoma Forestry Division, Washington, Oklahoma. The Oklahoma tree nursery was part of the following projects. The cooperative western nursery herbicide project, initiated in 1976, with cooperation among state, private and federal nurseries, Forest Service Research, State and Private Forestry, National Forest Systems, and State University of New York out of Syracuse. Twenty-eight nurseries in 12 states were involved in this effort which was broken down into three segments, each of three-year duration: the Pacific Coast started in 1976 (Stewart 1977, Owston et al. 1980, Owston and Abrahamson 1984), the Intermountain-Great Basin in 1977 (Ryker and Abrahamson 1980), and the Great Plains in 1978 (Abrahamson 1981, Abrahamson and Burns 1979) which the Oklahoma Nursery was a part of. In 1979 the Northeastern (NE) Area started an eastern nursery herbicide project in five states cooperating with Purdue University and State University of New York (SUNY) at Syracuse (Holt and Abrahamson 1980). In 1981 the NE Area expanded the eastern nursery herbicide project to the Great Lakes area with eight nurseries (state, federal and private) in three Lake States cooperating with SUNY (Abrahamson and Jares 1984).

During 1982, after the Great Plains segment of the cooperative western nursery herbicide project was completed, Oklahoma State (Abrahamson 1983) sponsored a nursery herbicide project of their own in cooperation with SUNY to help the nursery expand on the herbicide studies using different herbicides, tree species and sowing times. This study has continued on a yearly basis through 1987-88.

What is important in these projects is that all studies have similar objectives and methodologies and that information developed from one region or study project is supportive of that from other regions. In all these studies the objectives were to identify promising herbicides, develop data for product registration, and demonstrate safe and effective weed control practices for nursery seed beds.

METHODS

The nursery herbicide screening and demonstration projects were initiated as part of a three-year study. During the first year of the three-year study up to ten herbicides (eight of which are represented in Table 1) were screened on two to four major species of spring- and/or fall-sown conifers and/or hardwoods depending on the year involved in the study.

Treatments were applied to three- or six-foot long plots in four-foot wide nursery beds with a one-foot untreated buffer between plots. All treatments were installed in a randomized block design with three replications per species. Herbicides were applied with a modified Hudson®

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[1]Paper presented at the Intermountain Forest Nursery Association 1987 Annual Meeting. (Park Suite Hotel, Oklahoma City, OK, August 10-14, 1987.

[2]Lawrence P. Abrahamson is a Senior Research Associate, State University of New York College of Environmental Science and Forestry, Syracuse, NY.

Table 1. Herbicides, rates, and application timings used in the Nursery Herbicide Studies Conducted by SUNY at the Oklahoma Forest Regeneration Center.

Herbicide	Formulation	Manufacturer	(lb ai/A)	Application Timing		
				Inc[1] or Ps[2]	Pg[3]	Ps + Pg[4]
Diphenamid	Enide 50W; 90 W	Nor-Am	4.0	x	x	x
Trifluralin	Treflan 4EC	Elanco	0.75	x	–	–
DCPA	Dacthal W-75	SBS Biotech	10.5	x	x	x
Prometryn	Caparol 80W	Ciba-Geigy	1.0	x	x	x
Napropamide	Devrinol 50W	Stauffer	1.5/3.0	x	x	x
Bifenox	Mowdown 80W; 4F	Rhone-Poulenc	3.0	x	x	x
Oxyfluorfen	Goal 2E; 1.6E	Rhom & Haas	0.5	x	x	x
Oxadiazon	Ronstar G	Rhone-Poulenc	1.0	x	x	x
Napropamide & Bifenox	Tank Mix		1.0+3.0	x	x	x

[1]Pre-seeding incorporation: incorporated into top 2 inches of soil immediately before seeding.

[2]Post-seeding: broadcast applied to soil immediately after seeding.

[3]Post-germination: broadcast applied to soil 4 to 5 weeks after seedling emergence.

[4]Post-seeding plus post-germination: two separate applications at the full recommended rate.

type pressure hand sprayer, or a modified AZ plot pressurized sprayer equipped with check valves and four flat fan 8001 nozzles operated at 20 psi in a water carrier at a volume equivalent to 85 ppa (100 ml/three-foot plot). Granular formulations were ocularly applied from a hand shaker uniformly over the plot.

Pre-seeding incorporated treatments were applied no more than one day before seeding and incorporated into the top two inches of soil using a garden rake. Post-seeding treatments (Ps) were applied within two days after seeding, except on the fall-sown species which were applied any time after fall seeding but before mulching. Post-germination treatments (Pg) were applied four to six weeks after seedling emergence, except on the fall-sown species which were applied in the spring after seedlings had emerged.

Herbicidal damage to conifers/ hardwoods at the end of the first growing season was evaluated using a ten-point rating scale (0 is complete kill, 10 is no effect) proposed by Anderson (1963). Height of nine randomly selected seedlings and number of seedlings per foot in three randomly selected rows in each plot were also measured to determine chemical effects on germination, seedling growth and survival.

The objectives of the second-year studies were to evaluate the phytotoxicity and weed control effectiveness of three to four herbicides screened from the first-year study to be non-phytotoxic to the species tested and have reasonable weed control of weeds present at that nursery. Phytotoxicity was evaluated by using herbicidal damage ratings (Anderson 1963), seedling survival (number/foot) and height growth (cm). Dosages of 1X, 2X, and 1X + 1X of these herbicides were applied post-seeding and/or post-germination using three- or six-foot long plots in four-foot wide beds with a one-foot untreated buffer between plots. All treatments were installed using a randomized block design with three replications per species. Herbicide treatments were applied by small pressurized sprayer or hand shaker as was done the first year of these studies.

During the Great Plains part of the Oklahoma studies, weed control effectiveness of the best treatments were evaluated under operational use using nursery application equipment on 100-foot test plots. The herbicides were evaluated for weed control under operational use at the 1X rate of application applied post-seeding along, or post-seeding and post-germination. Phytotoxicity rating, survival and height measurements were also recorded from these operational plots.

RESULTS AND DISCUSSION

Earlier results from the Oklahoma nursery studies has been reported in a similar manner (Abrahamson 1984, 1986). Phytotoxicity data from all Oklahoma studies through 1987 is presented in Tables 2-12, listed by herbicides tested under each species. The tables are summaries of all the phytotoxicity studies and indicate; 1) those fall- and/or spring-sown seedlings where the herbicide has been safely applied at rates indicated without stunting or germination reduction (x); 2) herbicides that appear to be promising at rates indicated, but because of possible phytotoxic problems implied in some of our studies, these should be thoroughly tested before using at your nursery (o); 3) herbicides that should not be used

at rates indicated because of severe phytotoxic damage (-). One herbicide that should be elaborated on is napropamide. Napropamide is used at the lower rate (1.5 lbs ai per acre) when the nursery soil has below 1 percent organic matter, otherwise the higher rate (3.0 lbs ai per acre) is normally used. Napropamide is safe to use post-seeding on most spring-sown conifer species tested, but caused severe stunting when applied post-seeding to fall-sown conifer species in the Lake States study. Napropamide applied post-germination to both spring- and fall-sown conifers caused no phytotoxic problems.

Weed control expressed in terms of hand-weeding time, or "how much time can herbicides save you versus hand-weeding" is one of the most important aspects of these studies. In the Great Plains study (Abrahamson 1981) on spring-sown species the post-seeding applications were as effective as the post-seeding plus post-germination applications for total season weed control. The Forest Regeneration Center in Oklahoma is an example (Abrahamson 1983) of the type of savings in time and money that can be expected from these herbicides when used in forest tree nurseries.

Hand weeding time at the Oklahoma Forest Regeneration Center during 1981 was reduced by an average of 80 percent for all herbicides applied only in the spring (Ps) while those applied in both the spring and a second application five to six weeks later (Ps + Pg) reduced hand weeding time by an average of 87 percent. Based on minimum wage of $3.35 per hour, this would amount to an average gross saving of $4,600 per acre of seedbed (without figuring in cost of herbicide or application costs) weeded six times with a mean weeding time of 283 man hours per acre untreated seedbeds at Norman (Abrahamson 1983).

SUMMARY

There have been numerous trials, studies and tests of various herbicides at many different nurseries that have demonstrated the safe and effective use of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin, and prometryn on various conifer and/or hardwood first year seedling nursery beds. These herbicides have reduced the time required to hand-weed nursery beds by 80-87 percent when applied at sowing time alone or with a second application four to six weeks later. Over $4,000-$7,000 per acre of seedbed could be saved by using these herbicides over hand-weeding alone.

However, the safety and effectiveness of any herbicide should be tested at each nursery before operational use. These herbicide trials are urged because there is a strong possibility of differential results from varied interactions of different mixtures of tree and weed species, soil and climatic factors, and cultural practices at different nurseries. If a particular herbicide has never been used at your nursery, several years of trials are advisable because of variations in effects caused by different weather conditions. Trials should include "double doses" to evaluate the safety limits on crop seedlings and leave an untreated control to properly evaluate the effects of the herbicide.

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TABLE 2: Phytotoxic effects of herbicides tested on first year loblolly, shortleaf and Austrian pine nursery beds.

LOBLOLLY PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

SHORTLEAF PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
napropamide	*		x		
oxyfluorfen	*		x		
bifenox	*		x		
napropamide & bifenox	*		x		

AUSTRIAN PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		o	x	o
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 3: Phytotoxic effects of herbicides tested on first year ponderosa and Scotch pine nursery beds.

PONDEROSA PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
napropamide & bifenox	*		x	x	x

SCOTCH PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
\- = severe phytotoxic effects, <u>Do Not Use</u>.

TABLE 4: Phytotoxic effects of herbicides tested on first year eastern red cedar, and white cedar nursery beds.

EASTERN RED CEDAR

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	o	x	o
oxadiazon		*	x	x	x
trifluralin		*	x		
napropamide & bifenox		*	o	x	o

WHITE CEDAR

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	o	x	o
napropamide		*	o	x	o
oxyfluorfen		*	-	x	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
\- = severe phytotoxic effects, <u>Do Not Use</u>.

TABLE 5: Phytotoxic effects of herbicides tested on first year black walnut, and pecan nursery beds.

BLACK WALNUT

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	o	o	o
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		

PECAN

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
bifenox		*	x	o	o
prometryn		*	x	o	o
napropamide & bifenox		*	x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 6: Phytotoxic effects of herbicides tested on first year euonymus, and hackberry nursery beds.

EUONYMUS

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
diphenamid		*		o	
oxadiazon		*		x	
bifenox		*	o		
prometryn		*	o		
napropamide & bifenox		*	o		

HACKBERRY

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
napropamide		*		x	
diphenamid		*	o	x	o
oxadiazon		*		x	

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 7: Phytotoxic effects of herbicides tested on first year lacebark elm, and sycamore nursery beds.

LACEBARK ELM

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	
napropamide	*		o	x	o
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-	o	-
oxadiazon	*			x	
prometryn	*		-	-	-
trifluralin	*		o		
napropamide & bifenox	*		-	o	-

SYCAMORE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	x	-
napropamide	*		o	x	o
oxyfluorfen	*		-		-
diphenamid	*		o	x	o
bifenox	*		-	o	-
oxadiazon	*			x	
prometryn	*		-	-	-
trifluralin	*		o		
napropamide & bifenox	*		-	o	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
\- = severe phytotoxic effects, <u>Do Not Use</u>.

TABLE 8: Phytotoxic effects of herbicides tested on first year redbud, catalpa, and silver maple nursery beds.

REDBUD

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		-	x	-
diphenamid	*			x	
bifenox	*		o	o	o
oxadiazon	*			x	
prometryn	*		x		
trifluralin	*		o		
napropamide & bifenox	*			o	

CATALPA

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
diphenamid	*			x	
oxadiazon	*			x	
prometryn	*		x		
trifluralin	*		-		

SILVER MAPLE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	x	-
napropamide	*		x	x	x
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-	o	-
oxadiazon	*			x	
prometryn	*		x	-	-
trifluralin	*		-		
napropamide & bifenox	*		-	o	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
\- = severe phytotoxic effects, <u>Do Not Use</u>.

TABLE 9: Phytotoxic effects of herbicides tested on first year green ash, Russian olive, and black locust nursery beds.

GREEN ASH

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		o	o	o
prometryn	*		x		
oxadiazon	*			x	
trifluralin	*		o		
napropamide & bifenox	*		-	o	-

RUSSIAN OLIVE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		x		
napropamide & bifenox	*		-	x	-

BLACK LOCUST

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
bifenox	*		o	o	o
prometryn	*		o		
oxadiazon	*			x	
trifluralin	*		-		
napropamide & bifenox	*			o	

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 10: Phytotoxic effects of herbicides tested on first year baldcypress, and osage-orange nursery beds.

BALDCYPRESS

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
bifenox	*		x	o	o
oxadiazon	*			x	
prometryn	*		o		
trifluralin	*		x		
napropamide & bifenox	*			o	

OSAGE-ORANGE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		o	x	o
bifenox	*		o	o	o
oxadiazon	*			x	
prometryn	*		x		
trifluralin	*		o		
napropamide & bifenox	*			o	

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 11: Phytotoxic effects of herbicides tested on first year mulberry, and autumn olive nursery beds.

MULBERRY

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	o
napropamide	*		-	x	-
bifenox	*		-	o	
oxadiazon	*			x	
prometryn	*		-		
trifluralin	*		x		
napropamide & bifenox	*			o	

AUTUMN OLIVE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*			x	
prometryn	*		x		
trifluralin	*		x		
napropamide & bifenox	*			x	

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
\- = severe phytotoxic effects, Do Not Use.

TABLE 12: Nursery summary of tree species and herbicides utilized in the Great Plains and Northern United States nursery herbicide studies from 1978 to 1987.

Nursery (Ownership)	Species Studied	Sown F/S	Herbicides Tested
Oklahoma Forest	Austrian Pine	S	DCPA
Regeneration Center	Loblolly Pine	S	bifenox
[Norman Nursery]	Shortleaf Pine	S	oxyfluorfen
(State of	East. Red Cedar	F	trifluralin
Oklahoma)	Black Locust	S	diphenamid
	Sycamore	S	napropamide
	Lacebark Elm	S	napropamide+bifenox
	Hackberry	F	oxadiazon
	Euonymus	F	prometryn
	Russian Olive[1]	F	butralin[1]
	Silver Maple	S	chloramben[1]
	Mulberry	S	chloroxuron[1]
	Pecan	F	
	Catalpa	S	
	Redbud	S	
	Autumn Olive[1]	S	
	Green Ash[1]	S	
	Baldcypress[1]	S	
	Osage-orange[1]	S	

1 Tested only one year or less.

Use of Sulfur to Correct Soil pH[1]

Donald H. Bickelhaupt[2]

Abstract.-- The addition of 1780 lbs/ac of sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in a temporary decrease in soil pH. Seedling quality variables of Norway spruce were related to soil pH at time of sowing.

INTRODUCTION

The New York State Department of Environmental Conservation's Saratoga Tree Nursery, located at Saratoga Springs, New York, currently produces four to five million bareroot conifer seedlings annually (Scholtes 1985). The 100 acre nursery is located on deep loamy sand (80 to 90% sand with 5 to 10% clay). In the past 10 years the nursery has experienced problems in producing high quality seedlings of some species in some sections of the nursery. Problems encountered are poor seed germination, early seedling survival and many of the seedlings grown were stunted and chlorotic (Plumley 1986).

Between 1973 and 1977, the problem areas had received two to 12 inches of composted horse manure, including barn sweeping. This organic material was applied to the sandy soil to improve cation exchange, moisture holding capacity, and the amount of available nutrients. Laboratory analysis of several samples of material applied in 1973 indicated that the pH of the material was 8.16. Elemental analysis indicated that the material was very heterogeneous. Calcium and magnesium concentrations averaged 3.6% and 1.7%, respectively. The concentrations of nitrogen, phosphorus and potassium were 0.8%, 0.2% and 0.7%, respectively. The high pH, and high concentration of calcium and magnesium were the results of lime being sprinkled daily on the floors of the stables to control the odor of urine.

A single, six inch application of composted horse manure in 1974, to one section of the nursery, increased the soil organic matter from 5.0% to 8.0% during the three years following application. The organic matter concentration had returned to approximately pre-treatment level by 1982. Soil pH increased from 5.7 to 7.2 as a result of the single, six inch application of manure. Soil pH was 7.0 twelve years after applying manure.

Soil pH above the recommended range of 5.5 to 6.0 is a concern for nursery managers because of potential problems with damping-off and nutrient imbalance. Damping-off is favored in cool and wet, neutral to basic soils containing large amounts of organic matter (Manion 1981). Nutrients, such as potassium and ammonium, become fixed in soils with a high pH and are, therefore, unavailable to plants. However, phosphorus availability is greatest when soil pH is between 6.0 and 7.0. Solubility of micronutrients increases with acidity and become toxic when soil pH is too low (Tinus 1980). Therefore, soil pH should be maintained within the range where nutrients are available for plant growth but the micronutrients are not at toxic levels.

Some conifer species are intolerant to soil pH above 6.0. Mean total dry

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[1]Paper presented at the Intermountain Forest Nursery Association 1987 Annual Meeting. Park Suite Hotel, Oklahoma City, OK. August 10-14, 1987.

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weight of red pine (Pinus resinosa Ait.) has been shown to decrease as soil pH increased from 5.4 to 7.8 (Armson and Sadreika 1979). The weight of shoots and roots of greenhouse grown Douglas fir (Pseudotsuga menziesii (Mirb.) Franco), was greatest when soil pH was 5.5 (van den Driessche 1979). Height growth of Norway spruce (Picea abies (L.) Karst.) has been shown to be related to soil pH with the tallest seedlings being produced in soil with a pH of 4.5 (Benzian 1965). Soil pH must be maintained within the recommended range of the species to produce an adequate number of high quality seedlings per unit area.

Use of Sulfur to Reduce Soil pH

The amount of sulfur required to reduce soil pH to a certain value varies with initial pH and the amount of colloidal material in the soil. In general, an application of 500 lbs/ac of granular sulfur is expected to decrease soil pH by 0.5 units in the surface six inches of sandy nursery soils (White et al. 1980). To change soil pH from 7.5 to 6.5, the Western Fertilizer Handbook (1980) recommends the addition of 500, 800 and 1000 lbs/ac of sulfur to a sandy, loam and clay soil, respectively. Stoeckeler and Arneman (1960) suggested that 870 lbs/ac of sulfur would be needed to lower the pH of a silt loam soil from 7.0 to 6.0 and 1525 lbs/ac of sulfur would be required to lower the soil pH from 7.0 to 5.5. To prevent detrimental effects to seedlings, the application of sulfur to a sandy nursery soil should not exceed 750 lbs/ac (Armson and Sadreika 1979).

Sulfuric acid has been shown to be more effective than granular sulfur in reducing soil pH but the results are not permanent (van den Driessche 1969). In contrast, sulfur reacts slowly with the soil to reduce soil pH but the change is considered permanent (Tinus 1980). Utilizing this information, a study was established in the problem areas at the Saratoga Tree Nursery in an attempt to reduce soil pH and improve seedling quality. The application of a combination of sulfuric acid and granular sulfur was considered as a possible method to quickly reduce soil pH and maintain the soil pH between 5.5 and 6.0.

METHODS

Study plots had received a single six inch application of composted horse manure in 1974. The soil pH increased from 5.7 to 7.2 and remained above 6.9 until 1983 as a result of this single application (Table 1). In addition, the application of composted manure increased the level of organic matter to over 8% and the concentration of exchangeable calcium was as high as 2500 ppm. In 1983 the organic matter concentration had decreased to 4.5%, whereas the concentration of exchangeable calcium remained high (1900 ppm). The cation exchange capacity was 10.2 meq per 100 g and the base saturation was 114% in 1983.

A single application of granular sulfur was applied at the rate of 0, 890, 1780, 2670 and 3560 lbs/ac in October 1984. During the same period, concentrated sulfuric acid was applied at the rate of 890 and 1780 lbs/ac of

Table 1. Effects of applying six inches of composted lime-treated horse manure on soil properties at the Saratoga Tree Nursery, New York.

Year	pH	OM	N	P	K	Ca	Mg
		---- % ----		------------- ppm -------------			
1974[1]	5.7	3.6	0.06	83	28	396	31
1975	7.3	9.1	0.21	297	462	1216	338
1976	7.0	8.4	0.21	250	210	1426	355
1977	6.9	9.1	0.22	278	178	2509	549
1983	7.1	4.5	0.15	230	76	1900	231

[1] Horse manure was applied after the 1974 samples were collected.

sulfur. In addition, two combination treatments were established with granular sulfur and sulfuric acid each being applied at the rates of 890 and 1780 lbs/ac of sulfur. Each treatment was replicated three times. Norway spruce seeds were sown eight months after the application of sulfur.

Soil samples of the surface six inches were collected before treatments were applied, at time of sowing Norway spruce seeds, at the end of each growing season, and during the spring of the second growing season. Number of seedlings per foot of seedbed was determined in October, 1985 and October, 1986. Seedlings were lifted from the seedbeds in October, 1986, and measured for total height, root collar diameter and root volume (Burdett 1979). Additional seedlings were lifted in April, 1987, and measured for total height and root collar diameter. Ten seedlings from each nursery treatment plot were used for root growth capacity determination in April, 1987. Root growth capacity was determined by counting the number of white root tips per seedling after growing in the greenhouse for 28 days (Ritchie 1985).

RESULTS

Soil pH in the study area was 6.5 before treatments were applied. This soil pH was lower than the observed 6.8 to 7.0 found in other parts of the problem area because of the application of 840 lbs/ac of sulfur in the spring before the study was established. At time of treatment, the organic matter concentration was 3.0%; cation exchange capacity was 7.2 meq per 100 g; and concentrations of exchangeable calcium and magnesium were 1097 and 138 ppm, respectively. The base saturation was 92%.

A significant decrease in soil pH was observed eight months after sulfur application (Table 2). The application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in further lowering soil pH compared to the other sulfur treatments and was the only treatment to reduce the soil pH to the desired range. After 23 months, the higher combination treatment of sulfur plus sulfuric acid still had a significantly lower soil pH as compared to the control (Table 2).

Table 2. Changes in soil pH of treatment plots as a result of applying sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment Sulfur (lbs/ac)	Acid[1] (lbs/ac)	Months since treatment: 0[2]	8	12	20	23
		pH				
0	0	6.5 a[3]	6.7 a	6.9 a	6.8 a	6.9 a
890	890	6.5 a	6.3 b	6.7 ab	6.6 ab	6.7 ab
890	0	6.5 a	6.3 b	6.4 abc	6.8 a	6.7 ab
0	890	6.5 a	6.3 b	6.4 abc	6.7 a	6.7 ab
1780	0	6.5 a	6.3 b	6.2 bcd	6.6 ab	6.5 ab
2670	0	6.7 a	6.2 b	6.2 bcd	6.5 ab	6.5 ab
3560	0	6.6 a	6.0 b	6.1 cd	6.5 ab	6.4 ab
0	1780	6.5 a	6.0 b	6.2 bcd	6.5 ab	6.6 ab
1780	1780	6.5 a	5.5 c	5.6 d	6.1 b	6.1 b

[1] The acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Month 0 is at time of treatment.
[3] Values followed by the same letter within a column are not significantly different at P = 0.05.

Seedbed density at the end of the first growing season was influenced by the application of sulfur and sulfuric acid (Table 3). The plots that received sulfuric acid had significantly more seedlings per foot of seedbed compared to the control plots.

One beneficial aspect of many nursery soil amendments is the improvement in seedling quality. After two growing seasons seedlings growing in the plots which had received sulfur or sulfuric acid were significantly taller than the seedlings grown in the control plots (Table 4). Seedlings from the plots that received the heavier application of sulfur plus sulfuric acid were almost twice as tall as seedlings from the control plots. This mean total height represents all seedlings in the plot, including the culls.

Seedling root collar diameter at the end of the second growing season was also related to the application of sulfur (Table 4). The seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid had significantly larger root collar diameters than those in plots which received only sulfur or sulfuric acid. Seedlings in the control plots had the smallest root collar diameters.

Table 3. Seedlings per foot of seedbed as influenced by the addition of sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment Sulfur (lbs/ac)	Acid[1] (lbs/ac)	Seedlings per foot of seedbed 1-0	2-0
0	1780	120 a[2]	111 a
2670	0	100 ab	99 ab
1780	1780	99 ab	99 ab
0	890	96 b	95 abc
890	890	95 b	88 abc
890	0	86 bc	86 abc
3560	0	80 bc	80 bc
1780	0	64 cd	69 cd
0	0	53 d	53 d

[1] The acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Values followed by the same letter within a column are not significantly different at P = 0.05.

Root volume of the seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid was significantly greater than the control plots (Table 4). The heavier application rate of granular sulfur plus sulfuric acid produced more new roots tips than the control and, therefore, had a higher root growth capacity (Table 4).

Morphological measurements of seedling quality were related to soil pH at time of sowing Norway spruce seeds, but not with soil pH at the end of the first growing season or during the second growing season. Variables strongly correlated with soil pH at time of sowing were seedling height, root collar diameter and root growth capacity. The only variable weakly correlated with soil pH at the time of sowing was root volume.

Seedlings lifted in the fall of 1986 and spring of 1987 were graded to a minimum standard (root collar diameter being 0.09 inches and height being 3.5 inches) (Reese and Sadreika 1979). This grading indicated that over 60% of the seedlings grown in all sulfur plots were plantable, whereas less than 40% of the seedlings grown in the control plots were acceptable (Table 5). The heavier application of granular sulfur plus sulfuric acid resulted in the largest percentage of large and medium size seedlings and the smallest percentage of cull seedlings. The control plots had the largest percentage of culls. The percentage of large, medium and cull seedlings was strongly correlated to soil pH at time of sowing.

Another beneficial aspect of nursery soil treatment is the increase in the number of plantable seedlings per unit area. The largest number of plantable seedlings was produced in the plots that received the heavier application of granular sulfur plus sulfuric acid (Table 6). The lowest number of acceptable seedlings was produced in the control plots. The number of seedlings per foot of seedbed and the cull percentage have been shown to be related to sulfur treatment and soil pH at time of sowing Norway spruce seeds.

Table 4. Morphological characteristic of 2-0 Norway spruce seedlings as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York.

Treatment Sulfur	Acid[1]	Height (in)	Diameter (in)	Root volume (cm^3)	Number of white root tips
1780	1780	6.14 a[2]	0.100 a	2.28 a	100 a
0	1780	5.41 ab	0.086 bc	1.48 cd	79 ab
3560	0	5.29 bc	0.090 b	2.01 ab	49 bc
890	0	5.22 bc	0.086 bc	1.88 abc	52 bc
2670	0	5.01 bc	0.080 cd	1.17 bcd	65 bc
0	890	4.81 bc	0.079 cd	1.48 abc	59 bc
890	890	4.73 bc	0.082 cd	2.00 ab	63 bc
1780	0	4.46 bc	0.077 d	1.94 abc	53 bc
0	0	3.15 d	0.063 e	1.45 d	44 c

[1] Acid treatment is lbs/ac of sulfur as sulfuric acid.
[2] Values followed by the same letter within a column are not significantly different.

Table 5. Percentage of seedlings by size class as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York.[1]

Treatment Sulfur (lbs/ac)	Acid[2]	Large	Medium	Small	Cull
		Percent			
1780	1780	20.8 a[3]	26.8 a	32.9d	19.5 c
3560	0	13.8 b	14.8 bc	45.0 abcd	26.4 bc
0	1780	8.5 bc	16.1 b	42.3 abcd	33.1 bc
890	0	6.5 cd	15.8 bc	44.2 abcd	33.5 bc
2670	0	6.4 cd	13.4 bc	49.4 abc	30.8 bc
0	890	6.1 cd	14.4 bc	41.4 bcd	38.1 b
890	890	6.0 cd	8.0 bcd	58.4 a	27.6 bc
1780	0	3.0 cd	7.1 cd	53.0 ab	36.9 bc
0	0	0.6 d	2.4 d	34.6 cd	62.4 a

[1] Large size seedlings: >0.11" diameter and >7.5" height
Medium size seedlings: >0.10" diameter and >6.3" height
Small size seedlings: >0.09" diameter and >3.5" height
Cull seedlings: <0.09" diameter or <3.5" height
[2] Acid treatment is lbs/ac of sulfur as sulfuric acid.
[3] Values followed by the same letter within a column are not significantly different.

DISCUSSION

Results observed from the application of sulfur and sulfuric acid at the Saratoga Tree Nursery revealed that the soil pH at time of sowing and germination of Norway spruce seeds was important in producing quality seedlings. With the expection of root volume, all variables of seedling quality were affected by the soil pH at the time of sowing. The higher application rate of sulfur plus sulfuric acid yielded the lowest soil pH and the highest quality of seedlings.

These results differed from those observed at the Orono Nursery, located near Toronto, Ontario (Mullin 1964). At

the Orono nursery sulfur was applied at 0, 750, 1500 and 2250 pounds per acre, and at the end of three years, soil pH was reduced from 7.4 to 6.5, 6.0, 5.3 and 5.0, respectively. The reduction in soil pH of the control plots at the Orono Nursery may have been the result of the application of ammonium sulfate fertilizer the first year and ammonium nitrate the remaining two years of the study. With the exception of the 2250 lbs/ac treatment, seedlings produced in sulfur treated plots were taller, thicker (larger root collar diameter), and heavier with a lower top-root ratio than seedlings grown in the control plots. The 2250 lbs/ac treatment resulted in increased mortality of seedlings at the end of the first growing season.

The different results obtained in reducing soil pH with the high application rates of sulfur in the Ontario study and the Saratoga study may be related to the differences in cation exchange capacity and buffering capacity of the soils. Another contributing factor is that the organic matter applied at the Saratoga Tree Nursery contained large amounts of calcium and magnesium and served as a buffering agent. In fact, the application of six inches of composted lime-treated horse manure was equivalent to applying 3.5 tons per acre of lime.

Table 6. Number of plantable seedlings per foot of seedbed as influenced by the application sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment Sulfur (lbs/ac)	Acid[2] (lbs/ac)	Number of seedlings
1780	1780	79 a[2]
0	1780	74 ab
2670	0	68 abc
890	890	64 abc
3560	0	59 bcd
0	890	56 bcd
890	0	54 cd
1780	0	42 d
0	0	21 e

[1] Acid treatment is lbs/ac of sulfur as sulfuric acid.

[2] Values followed by the same letter within a column are not significantly different.

At the Saratoga Tree Nursery the reduction of soil pH by most treatments, however, was only for a short duration. The effect of the addition of 3560 lbs/ac of granular sulfur on soil pH is undetectable 20 months after application. In contrast, the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid showed a reduction of soil pH for at least 23 months. Primarily analyses indicate a treatment of 1780 lbs/ac sulfur plus 1780 lbs/ac sulfur as sulfuric acid is an acceptable method of lowering soil pH to obtain high quality seedlings.

Most of the study plots at the Saratoga Nursery that received sulfur or sulfuric acid had seedbed densities above the recommended 60 to 70 seedlings per foot of seedbed (Richards et al. 1973) at the end of the second growing season. The addition of sulfur plus sulfuric acid combined with the operational sowing rate crated conditions for high seedbed density. Consequently, individual seedling weight may decrease as seedbed density increases because of decreased seedling branching (Richards et al. 1973). By using the higher sulfur plus sulfuric acid treatment in conjuction with a lower sowing rates, desirable seedbed densities of high quality seedlings may be produced at a reasonable cost. A cost-benefit analysis needs to be conducted to examine economic benefits.

Results of the Saratoga study were also similar to other studies where the number and size of seedlings increased as a result of applying sulfuric acid (Hartley 1917). In fact, the application of sulfuric acid provided two benefits: (1) increased the soil acidity and (2) acted as a soil sterilizer. Before organic fumigants were developed, sulfuric acid was often used as a soil sterilizer (Stoeckeler and Slabaugh 1965). High populations of Fusarium reported by Plumley (1986) at the Saratoga Nursery may have been controlled by the application of sulfuric acid.

Although heavy applications of sulfur and sulfuric acid improved seedling quality at the Saratoga Tree Nursery, I must stress that these heavy application rates may not be acceptable at all nurseries and all species. Testing with small plots are needed to determine beneficial rates and any potential adverse effects.

CONCLUSIONS

1. The effect of applying six inches of composted lime-treated horse manure resulted in an increase in soil pH; a condition that has persisted for at least 12 years.

2. The heavy application of sulfur resulted in a signicant decrease in soil pH eight months after application. The greatest decrease in soil pH was achieved with the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid.

3. No significant differences were detected in soil pH twenty months after the application of sulfur or sulfuric acid. The combination of sulfuric acid plus sulfur decreased soil pH for at least 23 months.

4. The application of sulfur resulted in larger seedlings. The largest seedlings were produced in plots receiving the higher application rate of granular sulfur plus sulfuric acid.

5. Measures of seedling quality strongly correlated with soil pH at time of sowing Norway spruce seeds were height, root collar diameter and root growth capacity.

6. The application of sulfur reduced the percentage of cull seedlings and increased the number of seedlings per foot of seedbed.

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Certified Vendor Program[1]

Thomas G. Boggus[2]

Abstract.--With demands for timber resources and the cost of reforestation rising, inconsistency in planting standards, and several important groups impacted by the success or failure of each planting effort, the Texas Forest Service, in 1982, initiated its Certified Vendor Program. Now, through specific guidelines, inspection and training, more energy can be spent reforesting new NIPF lands, knowing current cases have been properly planted.

INTRODUCTION

The common goal of everyone involved in reforestation is to successfully establish a stand of healthy trees in the field. No matter what facet of the process you may be involved with, all efforts are concentrated at this one goal. As the demand for the resource continues to rise along with the costs of reforestation, the ability to reach this goal is becoming more and more challenging.

During the planting season of 1987, 1.12 million acres were artificially reforested in the southeastern United States on nonindustrial private forest lands. Using an estimated cost per acre of $115.00 for site preparation, seedlings and labor, that acreage figure represents an annual investment of over 128 million dollars in reforestation. The East Texas contribution amounts to 22,500 acres and $1.67 million annually with almost equal amounts being invested by the landowners and the three cost-sharing programs available in the state. These figures offer striking evidence that mistakes resulting in increased seedling mortality are extremely costly. In 1982, the Texas Forest Service began implementing a Certified Vendor Program in a effort to reduce mistakes during the time the trees leave the nursery and are planted in the field.

[1]Paper presented at the Intermountain Nursery Association. Oklahoma City, Oklahoma, August 10-14, 1987.

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REASONS FOR THE PROGRAM

Resource Demands

Results of the recently completed U.S.F.S. Forest Survey of East Texas reveal that removals of softwood have exceeded growth over the last few years (Fig. 1). Much of this trend, along with the potential for changing it, can be explained by looking to the nonindustrial private landowner (NIPF). This group owns approximately 60% of the commercial Forest land in Texas and yet has the poorest record historically in reforesting following a harvest.

Currently, only one acre in nine is reforest by NIPF landowners in Texas (Fig. 2). Given that figure, it is imperative that this important "acre" survive after being planted. Thus, one reason for the Certified Vendor Program is to improve the odds of survival through proper handling and planting methods. Of course, promotional and educational efforts continue to work towards seeing more of the other "eight acres" planted.

Program Consistency

A second reason for the vendor program was the need to bring consistency to the NIPF regeneration program. Prior to beginning the program, there were years where we were losing 8,000-12,000 acres per year when it could not be explained away by "dry weather." Seedling counts across East Texas revealed 500-550 seedlings per acre were being planted versus the 726 per acre called for in the management plans. Foresters had as many different ways of

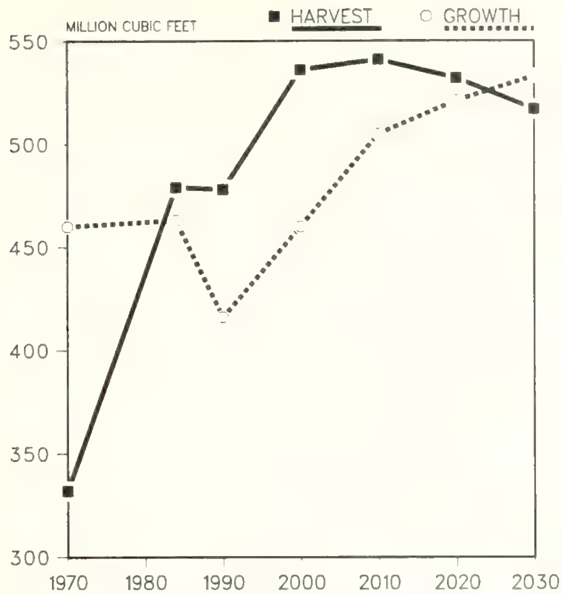

Figure 1.--Historic plus projected harvest versus growth figures for East Texas (USDA, 1987).

inspecting the jobs as the agency had foresters! Not to mention there was no standard means of comparing one vnedor or job to the next and, therefore, good vendors were not being rewarded for excellence and poor vendors were taking advantage of the system, the agency and the landowners.

Groups Impacted

Another imporant reason for the Certified Vendor Program is the group of people impacted by the success or failure of a tree planting job. This group includes landowners, funding institutions and planting vendors.

More than any other group, tree planting will have the greatest impact on landowners. Not only do they invest their hard earned savings into the project, they also make the decision to invest 20-30 years of their lives into these 6 to 8 inch tall trees. Survival is the first hurdle to pass but the next 19 risk-filled years are theirs to bear as well. The vendor program is aimed at helping clear that first hurdle with vigorous, healthy trees.

Since nearly all NIPF landowners in Texas take advantage of one of the three programs currently operating in the state that share the financial burden of reforestation, these funding institutions are also impacted by the success or failure of a job. Limited funds and the continued rise in reforestation costs mandate that the tracts requiring re-planting be kept to a minimum. The Certified Vendor Program helps reduce the amount of re-planting caused by poor planting methods.

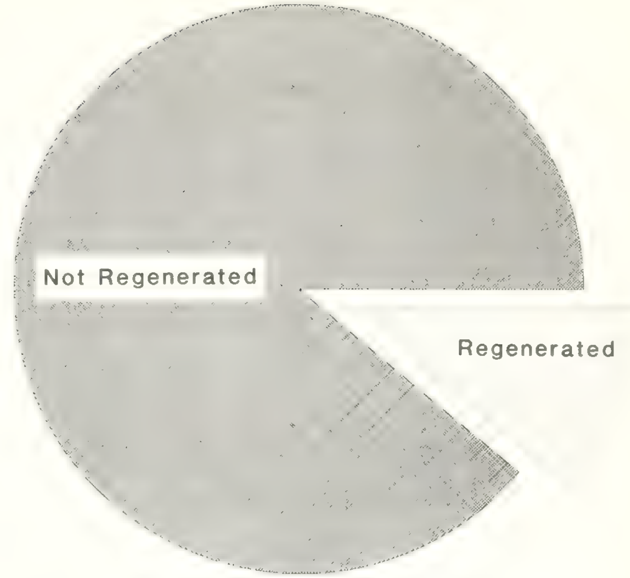

Figure 2.--Comparison of NIPF acres regenerated following harvests.

Tree planting vendors themselves are also impacted by their own planting jobs. A vendor has his/her livelihood and reputation riding on each planting effort. Since its inception, many vendors have commented on how this quality control type program is like having a "silent supervisor" on each NIPF tract their crews plant.

Cumulative Effect

Dr. S. J. Rowan (1987) recently released the results of study on the effects of tender loving care(TLC) from lifting to outplanting on survival. Although TLC produced positive results throughout the process, he concluded that nothing had a greater impact on survival than did proper handling and care during the actual transplanting in the field. This cumulative effect on survival is further magnified when consideration is given to the rather unique geographic location of Texas' commercial forestland. Planting pines in the western fringe area of the Great Southern Yellow Pine Forest demands extra care and, thus, the Certified Vendor Program.

KEYS TO SUCCESS

Having established the obvious need for the vendor program, the next step is to develop a clear set of objectives. The three main objectives of the Texas Certified Vendor's Program are:

1. Insure quality reforestation
2. Develop a qualified vendor community
3. Allocate work fairly

The keys to the success or failure in reaching these objectives lie in the methods chosen to implement the program.

Insure Quality Reforestation

Quite obviously, the primary objective of the Certified Vendor Program from its inception was to deliver a quality reforestation effort to NIPF landowners. Moving to meet this goal, however, required more care and planning than would the other two. The keys here are to develop a good set of technical guidelines, implement a uniform method of inspecting the work and train the personnel responsible for carrying out the program on the ground.

Technical Guidelines

The beginning point to insuring a quality reforestation effort is for all parties involved to be working within the same framework. In Texas, we developed a set of technical guidelines covering the three main topics of site preparation, planting and timber stand improvement. Each topic is further broken down into smaller sections which spell out in detail what practices are permitted, how to carry them out and what the minimum limits of acceptability are for each practice. Every forester, technician and vendor is supplied with, or has access to, a copy of these guidelines so everyone knows, in advance, what is expected of them.

For example, here is how "reforestation" is further broken down into sections. There are seven sections which include planting rates, planting methods, seedling care, protection of seedlings, environmental considerations, vendor certification and vendor completion requirements. Everyone involved with reforestation on any given NIPF tract is working under the same rules and knows the consequences for breaking them. Of course, these guidelines are only good as long as there is some way to verify they are being complied with, which means on site inspections.

Inspection

The strength and credibility of the vendor program center around the inspection process. Almost every NIPF tract planted in East Texas is inspected by a trained tree planting inspection crew. These two-man crews systematically check 1/100th acre plots over an entire area, with the number of plots per tract dependent upon actual tract size (table 1).

Upon arrival at each plot site, the plot is numbered and marked with a wire flag in case it is necessary to return to that particular plot. Next, the total number of trees per plot are counted by using a 1/100th acre tape or rope and that number is recorded on a data sheet. Then the trees within the plot are checked for "above ground problems" (table 2) such as debris in the hole or planted too shallow. Finally, before leaving a plot, two trees are carefully excavated outside of the plot itself to inspect for any below ground problems like severe root pruning or "J" rooting (table 2).

Table 1.--Number of plots taken based on the size of the tract and approximate distance between plots in Gunters chains.

Tract Size (acres)	# of Plots	Dist. (chains)
0-60	1 per ac	3.25
61-90	1 per 2 ac	4.50
91+	1 per 3 ac	5.50

Table 2.--A list of specific above and below ground problems inspection crews look for at each plot.

Above Ground Problems	
Debris in hole	Cull seedlings
Too shallow	Too deep
Not packed	Unidentified

Below Ground Problems	
Excessive angle	"J" rooting
"L" rooting	Twisted roots
Pruned improperly	Cull seedlings

Before leaving the planting site, the inspection is completed by checking seedling bundles and counting and culling two bundles of seedlings, if possible. The bags are checked for species type to insure the right species is planted on each tract and the bag dates for when the bundles left the cold storage. Vendors have 14 days to either plant the trees or heel them in after the seedlings leave cold storage. Failure to do so results in bag confiscation and replacement seedlings must be furnished by that vendor. The seedling bundle count provides important information to the nursery as to how many plantable trees per bag are leaving the nursery. This is especially important since the data is received during lifting and grading so adjustments can be made as needed.

Since the inspection process is so important to the success or failure of the program, some means of "inspecting the inspectors" or quality control is vital. In Texas, we have quality control people in each management area whose job it is to spot check every inspection crew

working in their area. The crews never know where or when the quality check will be performed and poor job performance could mean a severe reprimand or their jobs.

Training

From the previous section it becomes apparent that a virtual army of inspectors is needed. That entails training this army initially and then continuing to update them on any changes from year-to-year plus refresher courses. The source of manpower for these inspectors came from our forest technician ranks who were, up to this point, primarily considered fire fighters. Their number one priority is still to suppress wildfires, however wildfire suppression does not require the bulk of their time except for generally short periods of time during the year.

Tree inspection training requires about three days to complete. The first day is spent in a classroom session reviewing the technical guides, plot procedure, mathematics involved in working up the data, and other matters concerning the inspection of a tree planting job. The next two days are spent in the field in "hands-on" type exercises with individual instruction at each station. Both the classroom and field exercises have exams the trainees must pass prior to becoming a certified inspector.

Develop a Qualified Vendor Community

Approximately 22,500 acres of NIPF lands are reforested annually in East Texas. Even though this level of planting pails in comparison with some other southeastern states, it is impossible for the Texas Forest Service personnel to plant this acreage and undesired, even if it were possible. Therefore, it is imperative that a qualified community of vendors be developed to handle the work. To begin to accomplish this, we must once again turn to training.

As stated, each vendor interested in planting trees in NIPF lands in East Texas is supplied with a copy of our technical guidelines. Additionally, we require a vendor to attend one of the day-long meetings held at different locations and dates during the fall. During these meetings, the vendors have explained in detail the requirements of the program, technical guides, inspection process and other matters concerning planting season through a multimedia presentation and question-answer session. At the conclusion of every meeting, the vendors wishing to participate in the Certified Vendor Program sign an agreement stating they will plant according to the guidelines. The requirements are tough but fair and our list of vendors grows each year.

Allocate Work Fairly

The final objective to meet after everything else has been implemented is to find a means of allocating the work to the vendor community. The best method we have found is through the use of the sealed competitive bid system. Not only does this remove the agency from any bias in vendor selection, it also keeps reforestation costs down for the landowner due to vigorous competition. Landowners, not the Texas Forest Service, have the option to accept or reject the bids received on each tract. Since the vendors must meet minimum requirements under the program and vendors are not paid until these requirements are met, the landowner is assured of a quality planting job.

CONCLUSION

With the increasing demands for forest resources and planting mistakes resulting in reforestation failure becoming more costly, the Texas Forest Service has begun to take steps to meet both problems. In essence, we take this saying to heart, "you can achieve results two ways: expect it or inspect for it"! We expect a great deal from our own people and the vendors, but then we make inspections to insure we get it.

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Alternative Methods to Evaluate Root Growth Potential and Measure Root Growth[1]

W. J. Rietveld and Richard W. Tinus[2]

Abstract.--This paper reports experiments that compared root growth potential (RGP) testing methods, methods of quantifying root growth, and diagnostic ability of test methods. Factors that affect root growth in RGP tests are discussed. New root growth and plant water potential patterns of jack pine seedlings in pot, hydroponic, and aeroponic culture were similar, but new roots appeared first in hydroponic and aeroponic culture. The simplest method of quantifying root growth is to measure the number of roots longer than a minimum length. Electronic measurement of root area index is fast and well correlated with root number and length, but the equipment cost makes it most suitable for large operations. Test method and test length may affect results. Fourteen-day pot and aeroponic culture tests of jack pine seedlings subjected to root exposure treatments accurately diagnosed the weakened seedlings, but the seedlings recovered in 28-day tests, especially in aeroponic culture. For new applications, it is recommended that preliminary screening tests be run to determine the most suitable testing conditions.

INTRODUCTION

Root growth potential (RGP) is the most important measurable attribute of physiological quality because it quantifies the ability of seedlings to initiate and elongate new roots promptly and abundantly after transplanting. RGP is unique because it integrates an array of physiological factors into a single biologically meaningful estimate of performance potential -- the ability to grow new roots. Much information has been published on RGP in the past few years. Available evidence to date indicates a strong relation between RGP and field survival and growth (Ritchie 1985). Factors that affect the development and expression of RGP were extensively reviewed by Ritchie and Dunlap (1980), the relation of new root growth to several seedling and environmental factors was discussed by Carlson (1986), and the role of new root growth in the mechanism of transplanting stress was discussed by Sands (1984).

In contrast to most morphological quality measurements, which can be measured almost instantaneously, physiological quality attributes take time to measure (except for plant moisture stress). Consequently, it is not yet feasible to test stock and grade it physiologically before shipping. Until a faster method is available to estimate RGP, e.g. via a connection with cold hardiness (Ritchie 1985; Tinus, et al. 1986), we must be content to rely on present root growth tests to document RGP, and obtain the results in 2-4 weeks, usually after the seedlings have left the nursery.

Many people have hesitated to become involved in RGP testing because of: (1) equipment costs, (2) long test length, and (3) labor requirements and tedium of taking data. For the most part, these drawbacks are more imagined than real. The many variations on the original 28-day RGP test are summarized by Ritchie (1985). RGP tests may be shortened to as little as 7 days for certain species (Burdett 1979), and root growth may be quantified by new root number, length, volume, area index, or dry weight. In this paper we will focus on: (1) selection of methods to test the seedlings; (2) alternative methods to measure new root growth; and (3) the effects of testing

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method, test conditions, and test length on results.

COMPARISON OF TESTING METHODS

Although many different growing systems and media have been tried, the three main methods currently used to test seedlings are pot culture, hydroponic culture using an aquarium, and aeroponic culture using a root misting chamber. Pot culture is the traditional method (Stone 1955). It appears to be straight forward and inexpensive, but two important test conditions must be satisfied: (1) root temperature must be kept uniform, and (2) the growing medium must be well aerated. To provide a uniform root temperature, a growth room or water bath system is usually required, which raises the cost to a level comparable with other methods. Well-designed and relatively inexpensive hydroponic methods have recently been reported (DeWald et al. 1985, Palmer and Holen 1986). Hydroponic culture keeps the seedlings clean of growing medium, allows periodic observation of the progress of root growth, minimizes damage to new roots, and allows the test seedlings to be grown in fewer containers, while maintaining uniform root temperature and aeration within containers. It is important that aeration be gentle and uniform among containers, otherwise the agitation may inhibit root growth and increase variation. Aeroponic culture in a root misting chamber is another new technique. It was originally reported by Lee and Hackett (1976), refined by Harvey and Day (1983), and more recently refined by Rietveld and Tinus (1987). The root misting chamber has the same advantages as hydroponic culture, plus it is portable and provides a uniform temperature, humidity, and aeration environment for the roots in one container.

While developing the new root misting chamber, we needed documentation to show how the new device compares with existing methods for growing the test seedlings. To provide that documentation, we grew overwinter-stored 2+0 jack pine (Pinus banksiana Lamb) seedlings in pot culture, hydroponic culture, and aeroponic culture in the new root misting chamber, and compared new root production, among-seedling variation, and root size distribution. Potted seedlings were grown in a mixture of 1:1:1 sand/perlite/vermiculite with no fertilizer added. The hydroponic system consisted of tree holders laid across a large 20-cm-deep galvanized tank of water gently aerated through aquarium stones. The three growing systems were located in a growth room set at a constant 27° C temperature, 18 hour photoperiod, and light intensity of 165 uE/m^2/sec. The root misting chamber was also set at 27° C. Seedling root growth of 10 seedling samples was measured after 9, 11, 14, 16, 18, 21, 23, 25, and 28 days using a new root area index method (Rietveld and Tinus 1987). Number and length of new roots longer than 0.5 cm were also measured on day 28. Additionally, plant water potential of each test seedling was measured, using a pressure chamber, at the same time root growth was measured. Data were subjected to analysis of variance and Bartlett's test of homogeneity of variances.

New root growth was observed first in the root misting chamber and in hydroponic culture on day 9, then in pot culture on day 11 (fig. 1). Although seedlings grown in the root misting chamber had consistently higher levels of new root growth, the data were statistically indistinguishable from the hydroponic and pot methods on all measurement days, due to high among-seedling variation. The variances of the three methods, compared for the overall test and for days 14, 21, and 28, were likewise indistinguishable.

Root size distributions on day 28 for seedlings tested by the three methods are shown in figure 2. Although the patterns are similar for roots less than 15 cm long, seedlings grown in the root misting chamber and hydroponic culture had more long roots, reflecting the earlier and faster rooting apparent in figure 1. The response may also reflect the lack of soil resistance to root elongation.

The pattern of plant water potential in test seedlings is shown in figure 3. Average potential of seedlings taken from the cooler on day zero was -0.5 bar. Within 1 day in the growth room, potential dropped (became more negative) to approximately -6 bars, bottomed at approximately -6.5 bars on day two, then gradually increased during the course of the test to the range of -3 to -4 bars. The increase in plant water potential was weakly correlated with the initiation of new roots (r= -0.34), and may be better explained by osmotic adjustment. There were no significant differences in plant water potential among the cultural methods on any of the measurement days.

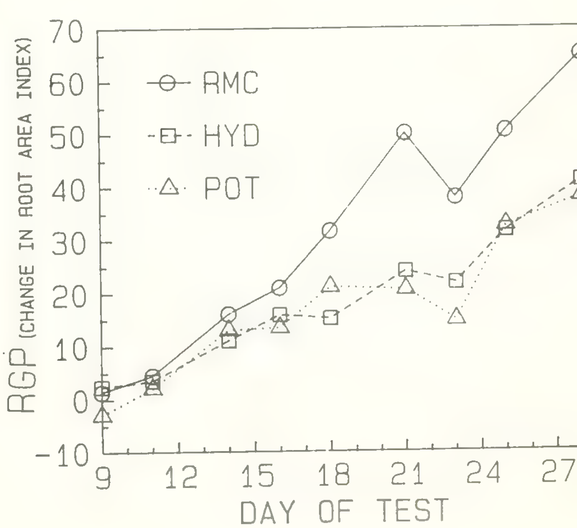

Figure 1. Root growth potential of 2+0 jack pine seedlings grown in aeroponic, hydroponic, and pot culture, quantified as change in root area index for nine test periods.

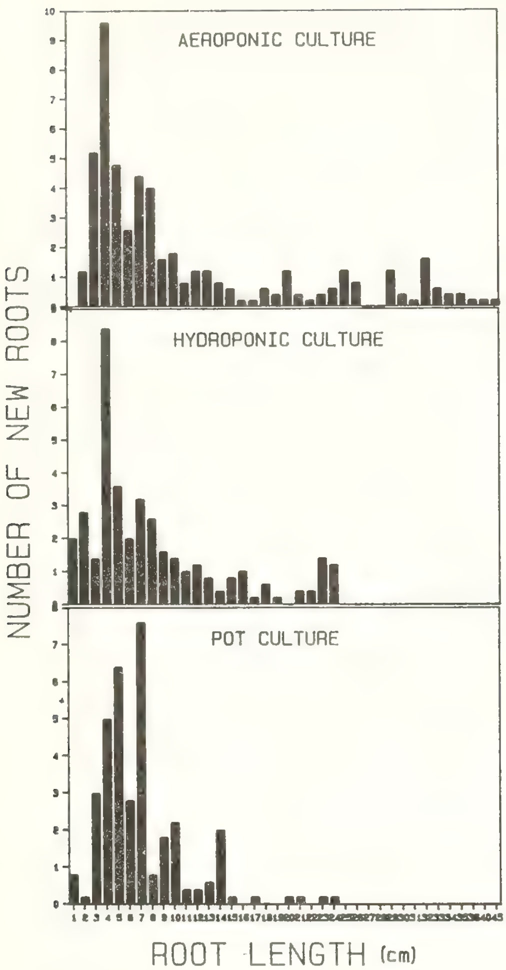

Figure 2. Size distribution of new roots of jack pine seedlings, on a per seedling basis, after 28 days of growth in aeroponic, hydroponic, and pot culture.

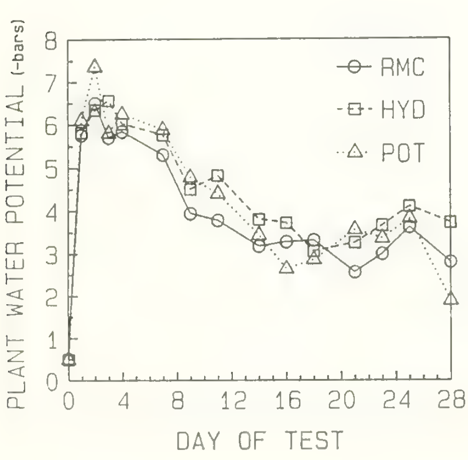

Figure 3. Plant moisture stress of 2+0 jack pine seedlings grown in aeroponic, hydroponic, and pot culture. Each point is the mean of 10 seedlings.

These data show that the three growing methods produce similar growth patterns for normal planting stock. Root growth was somewhat faster in the root misting chamber than in hydroponic or pot culture. For jack pine, 14 days appears to be the minimum test length to obtain an acceptable root growth response for evaluation.

COMPARISON OF METHODS TO MEASURE ROOT GROWTH

The task of quantifying new root growth may seem initially formidable when you look at a seedling that has up to 400 new roots on it, but the job is not as big as it looks. Researchers have devised many methods to lessen the task while still obtaining meaningful data. Originally both number of new roots and total length of new roots were measured. Eventually it was found that root number and root length are strongly correlated (Stone and Schubert 1959), so only number of roots longer than a minimum length was measured. Note, however that the correlation would be expected to decrease as test length increases because some of the new roots grow quite long (see fig. 2). Harvey and Day (1983) were the first to quantify new root growth in RGP tests by change in root area index using a Rhizometer (Morrison and Armson 1968), a photoelectric device developed for seedling morphology measurements in Ontario. Racey (1985) compared root measurement by root area index (using the Rhizometer), volume, and dry weight. He found strong correlations between the three quantification methods and the calculated area of new root tips, and recommended root volume because it was the easiest to measure. However, the Rhizometer has problems detecting new white roots at high light intensities (Racey 1985), and root volume determined by the Archimedes principle (measuring weight increase when the roots are dipped into a large beaker of water on a balance) has problems due to lack of repeatability of individual measurements (Ritchie 1985). A new root area index method for quantifying root growth in RGP tests was developed by the authors (Rietveld and Tinus 1987). The method is based on a microprocessor area meter (Delta-T Devices, Cambridge, England[3]), and involves placing an intact root system on a light box in view of a black and white TV camera. The image is scanned by the area meter, and a microprocessor totals all the line segments in the viewing area that are covered by roots. The method is very fast (up to 500 seedlings/day), but the equipment costs much more ($3670) than that needed to count the new roots manually.

To provide documentation for the microprocessor root area index method, we conducted a test to determine the relation among new root growth measured by change in root area index,

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[3]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

counted number of new roots, and measured length of new roots. To compare the methods over a range of RGP, we gave 50 jack pine seedlings root exposures of 0, 10, 20, 30, and 40 min by placing them in a large forced-air oven at 40° C. The seedlings were grown in a root misting chamber located in a greenhouse with maximum air temperatures ranging between 18 and 28° C, minimum air temperature of 15.5° C, photoperiod extended to 18 hours with high pressure sodium lamps, and light intensity ranging from 300 to 800 $\mu E/m^2/sec$. The root misting chamber temperature was set at 27° C, which is favorable for jack pine. After 17 days, new roots >0.5 cm on each seedling were measured manually, and all new roots were measured by the root area index method. Root growth measurements were compared by linear regressions using individual seedlings as observations (n=50). The coefficients of determination (r^2) for change in root area index on total number of new roots and total length of new roots were 0.88 and 0.90, respectively (fig. 4). Total number of new roots was closely related to total length of new roots (r^2=0.93). These strong relations indicate that measuring new root growth as change in root area index is a valid quantification method that provides a close estimate of actual root number and length.

Change in root area index may be a better estimate of rooting response than either root number or root length because (1) it measures all new roots, (2) it takes both root diameter and length into account, and (3) it detects root decrement as well as increment. However, the root area index method does not distinguish the origin of new roots and does not give any information on individual root size classes, i.e. the relative abundance of coarse and fine roots.

RGP TEST ENVIRONMENT AND SAMPLING

Although it is widely accepted that a uniform and favorable root environment is most important for conducting RGP tests, the shoot environment

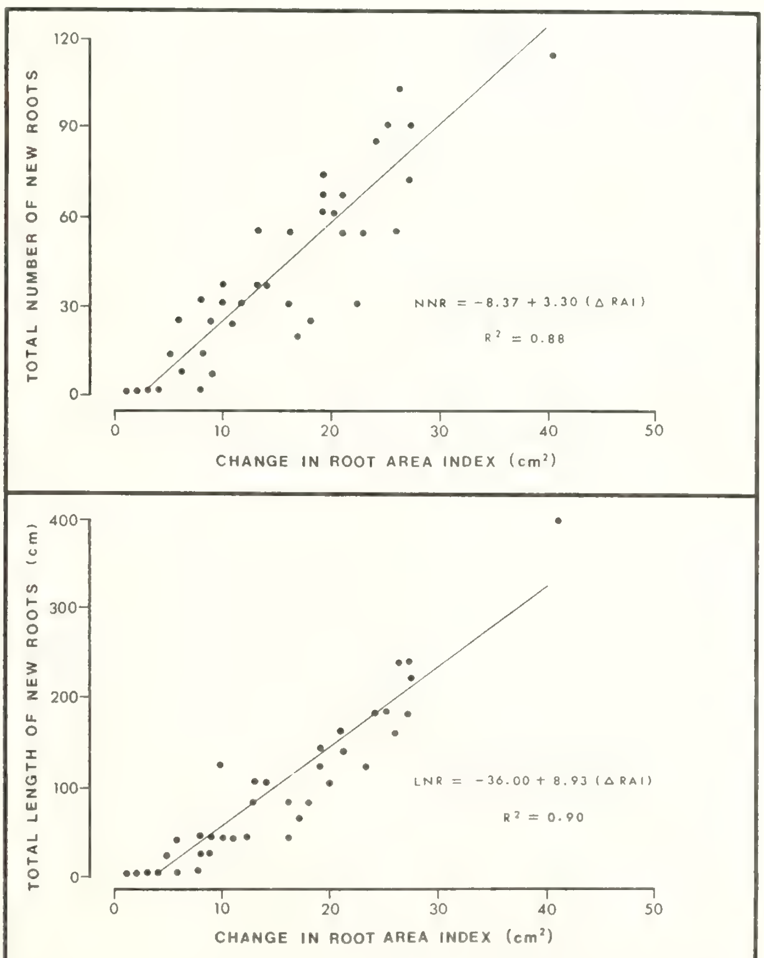

Figure 4. Regressions of root growth quantified by number of new roots (NNR) and length of new roots (LNR) on change in root area index (<>RAI), measured on the same seedlings. n=50. Several points represent multiple seedlings, especially those with zero NNR or LNR.

should also be favorable and repeatable when a series of RGP tests are run and the results compared. Abod et al. (1979) found that RGP of Pinus caribaea Mov. and P. kesiya Royle ex Gordon seedlings was optimized at air and soil temperatures between 24 and 30° C, and light intensity of approximately 50% of full sunlight (500-750 $\mu E/m^2/sec$). The optimum temperature for seedling root growth of many North American species is near 20° C (Ritchie 1985). Root growth potential tests are commonly run at elevated root and shoot temperatures and extended photoperiods. These conditions are well beyond the normal environment when seedlings are transplanted, but test results are obtained in a shorter time. Significant seed source and family differences in optimum temperature for root regeneration have been documented within a species (Carlson 1986, DeWald and Feret 1985, Jenkinson 1980, Nambiar et al. 1982). Therefore, it is advisable to experiment with root and shoot temperatures, and test length to determine the most suitable conditions for the species being evaluated, as well as seedlot or family variation in response to temperature. If seedlot or family variation is significant, it may be useful to adjust RGP to a base temperature (e.g. 20° C) for comparison.

Another factor to consider is seedling size. Seedlings with higher root volume have higher RGP (Carlson 1986), so it is important that the sample tested represents the range of seedling sizes in the stock lot. Note that selecting seedlings of uniform size for testing RGP would give a biased estimate of RGP if the average size of the sampled seedlings was not the same as the mean size for the stock lot. To obtain a true random sample that represents the range of seedling size and condition in the seedlot, the seedlings to be tested must be sampled from many locations in the population.

For normal bed-run stock, we consider a sample size of 25 seedlings to be minimum because variation is often high in RGP tests (Ritchie 1985, Sutton 1983). Depending on the uniformity of the test plants and the precision desired, 50 seedlings or more may be necessary. Very uniform plant material, such as stock grown by family (e.g. from seed collected from a clone in a seed orchard), may require fewer test seedlings.

DIAGNOSTIC ABILITY OF THE TEST METHODS

An additional question that needs to be addressed is how do the methods compare in diagnosing stock that differs in vigor -- will the same conclusions be reached using different testing methods? To answer this question, we generated several levels of seedling vigor by subjecting jack pine seedlings from a common seedlot to root exposures of 0, 10, 20, 30, 40, and 50 min at 40° C in a large forced-air oven. We then assigned 15-seedling random samples to 14-day and 28-day RGP tests in the root misting chamber and pot culture. The experiment was conducted in a large root misting chamber (0.9 m wide x 3.7 m long) located in a greenhouse under the same environment as the previous experiment. Potted seedlings were suspended in the root misting chamber so that the root temperature in the pots was maintained at the same temperature as the misting chamber. New root growth was quantified by the root area index method described above.

The results were quite surprising. At 14 days the root misting chamber and pot culture methods gave the same diagnosis (fig. 5): i.e. RGP of all root exposure treatments was significantly lower than the control (0 min root exposure). The root growth difference between control and root exposed seedlings was substantially higher when seedlings were tested in the root misting chamber (fig. 5). In the 28-day test, however, seedlings from many of the root exposure treatments recovered, especially in the root misting chamber. The testing methods did not give the same diagnosis in the 28-day test: in pot culture, only seedlings root exposed for 10 min recovered (n.s. from control), while in the root misting chamber seedlings in all root exposure treatments recovered (all n.s. from control).

It appears that under some conditions the root misting chamber environment may be too favorable for root growth, so that weakened seedlings may recover in longer tests (28 days) and show acceptable RGP. This was true to some extent for the potting method as well. In a 14-day test, however, the two methods were equally capable of diagnosing the weakened seedlings. These results suggest that tests should be no longer than necessary to detect differences in quality; longer tests may result in greater variation among seedlings, recovery of weakened seedlings, and more roots to measure. Additional research is needed to determine all the implications of test method and test length.

This experiment also demonstrated clearly the difference in root growth rates between the root misting chamber and pot culture. For the 0 min root exposure treatment, root area index increment at 14 days was 16.2 for the root misting chamber and 12.1 in pot culture (significant at $\alpha = 0.05$); at 28 days it was 60.6 for the root misting chamber and 26.8 in pot culture (significant at $\alpha = 0.005$).

SUMMARY AND CONCLUSIONS

1. RGP is the most important measure of seedling physiological quality because it integrates an array of attributes into a single biologically meaningful measure - the ability to grow new roots. However, physiological grading is still not practical because RGP testing is not immediate like morphological measurements

2. RGP testing in pot culture, hydroponic culture, and aeroponic culture (root misting chamber)

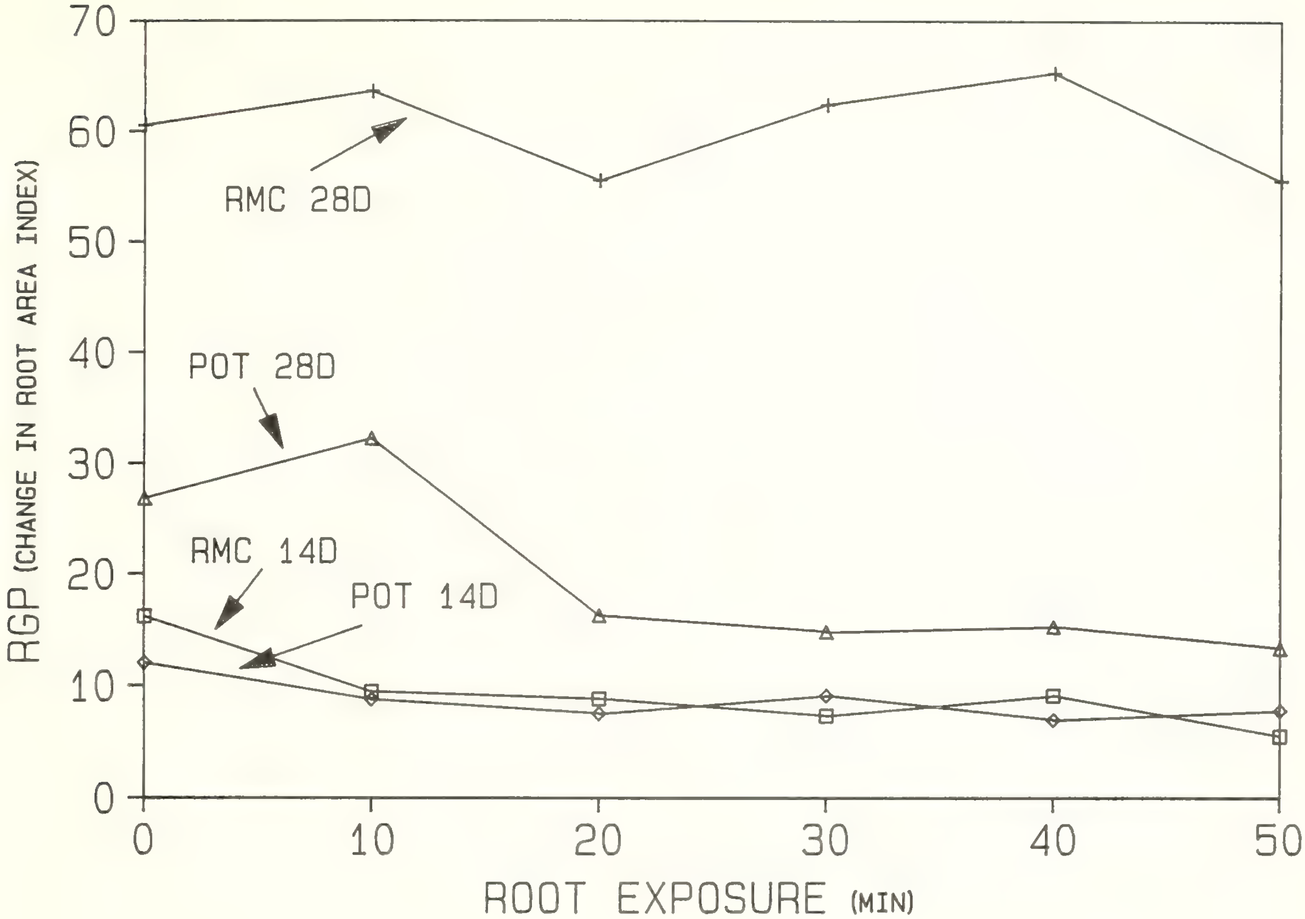

Figure 5. Root growth potential, measured as change in root area index, of 2+0 jack pine seedlings grown in aeroponic and pot culture for 14 and 28 days.

gives similar root growth patterns. New root growth was observed first in hydroponic and aeroponic culture. The three methods require approximately the same investment in equipment when maintenance of uniform root temperature is taken into account.

3. For smaller numbers of seedlings, it appears that the simplest and least expensive method of quantifying root growth is to count the number of new roots longer than a minimum length. This approach is based on a strong relation between root number and root length. The relation would be expected to weaken with longer test periods (some roots grow very long), but should still be satisfactory. Measurement of root area index increment is the easiest and fastest method of quantifying new root growth, and is well correlated with root number and length, but the equipment cost makes it more suitable for large operations.

4. Test method and test length may affect test results. Seedlings weakened from root exposure treatments were found to recover in 28-day aeroponic tests, and to some extent in pot culture. However, both methods accurately diagnosed differences in seedling vigor in 14-day tests.

5. Root temperature, light intensity, seedling size, test method, test length, species, and seed source/family within species have all been reported to affect RGP. If a series of RGP tests will be run and the results compared, it is advisable to run preliminary screening tests before a set of testing conditions is established. The "best" testing method and conditions are those that meet specific needs and objectives, and can distinguish differences in physiological quality in the least amount of time.

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Comparison of Time and Method of Mist Chamber Measurement of Root Growth Potential[1]

Karen E. Burr, Richard W. Tinus, Stephen J. Wallner, and Rudy M. King[2]

Abstract.--Container-grown ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were cold acclimated and deacclimated in growth chambers over 19 weeks. Weekly whole-plant freeze tests and 7- and 14-day root growth potential (RGP) tests indicated 7-day RGP results were misleading during cold acclimation and that the 14-day test period was preferable. During cold deacclimation, both RGP test periods were suitable. Quantification of RGP as total length and total number of new roots per seedling were nearly equally informative from budset to bud break, independent of the length of the RGP test.

INTRODUCTION

Root growth potential (RGP) is the ability of a tree seedling to initiate and elongate new roots when placed into an environment favorable for root growth (Ritchie 1985). It is a measure of seedling physiological quality and vigor. To become established in the field after outplanting, seedlings must be able to utilize new soil reserves of water and nutrients as those reserves in immediate contact with existing roots are depleted. New roots must be produced to accomplish this. Seedlings with a high capacity to produce new roots are likely to become established more rapidly and with less stress than comparable seedlings with a low RGP. For this reason, RGP measurements made prior to outplanting have been found to be positively correlated with the field survival and growth of many species of forest tree seedlings (Burdett 1979, Burdett et al. 1983, Jenkinson 1980, Ritchie and Dunlap 1980, Stone et al. 1961). Measurement of the RGP attribute is currently thought to be the most reliable predictor of field performance of the various seedling quality tests available (Ritchie 1985).

RGP is commonly measured using one of three approaches: the pot test, a hydroponic system, or an aeroponic system. In the pot test, originally developed by Stone (Stone 1955, Stone and Jenkinson 1970, Stone and Schubert 1959), seedlings are potted, several per container, and maintained for 28 days at 20°C under a 16-hour photoperiod and as near field capacity as possible. Seedlings are washed from the medium to assess root growth. While this technique is successful, it has disadvantages (Ritchie 1985). Considerable time is required before results are available, and plant maintenance during that time is expensive. Potting and unpotting of seedlings is not only labor intensive, but requires large quantities of media, can result in root system damage, and does not permit examination of the root system prior to the end of the test period. Burdett (1979) addressed the problem of the lengthy test period by developing a 7-day test in which root growth was accelerated by increasing the day/night temperatures to 30°/25°C. The 7-day and 28-day test results are well correlated in a number of conifers (Ritchie 1985), though not in all species (Ritchie 1984).

The hydroponic system uses temperature-controlled aerated water baths made from aquariums painted black and covered with lids which support the seedlings with the roots submerged. Winjum (1963) used a 28-day test period, while others have successfully shortened the test to between 15 and 21 days (DeWald et al. 1985, Rose and Whiles 1985, Sutton 1980). Hydroponic systems eliminate the disadvantages associated with potting and unpotting of seedlings. Additionally, this technique requires 50% less bench space than the pot test, and the roots are easily measured because they remain clean and unbroken. Ritchie (1984, 1985) found that seedlings tested hydroponically produced about the same length and number of new roots as similar in concurrent pot tests. However, hydroponic culture of tree seedlings can result in steadily decreasing xylem water potential and minimal new root production

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(Rietveld 1986). An additional problem suspected with the hydroponic system is an unsuitability for the testing of container stock because of failure to adequately aerate the root balls.

The aeroponic system includes the use of mist boxes or chambers in which the seedling root systems are suspended (Day 1982, Hileman 1986). A 28-day test period has been used with Pistacia chinensis (Lee and Hackett 1976), but Tinus et al. (1986) have successfully shortened the test to 14 days with conifers by using a warm water mist to accelerate root growth. The aeroponic system has all the desirable characteristics of hydroponics plus some important additional advantages. Seedlings in mist chambers initiate new roots 1 week sooner than potted seedlings (Rietveld 1986) and produce greater numbers of regenerating roots than seedlings in concurrent pot tests (Lee and Hackett 1976). This permits shorter test periods. In addition, the aeroponically-created root environment maintains xylem water potentials similar to those of potted seedlings (Rietveld 1986) and is ideal for the testing of container stock (Tinus et al. 1986). The aeroponic system is rapidly becoming the method of choice for these reasons. USDA Forest Service initiated aeroponic RGP testing at all 11 of its nurseries in 1987.

The most desirable parameter of root growth is total new root surface area, because it is proportional to water and nutrient uptake ability (Newman 1966). However, root surface area is not readily measured. Thus, RGP is usually quantified as total length and/or total number of new roots per seedling (Ritchie 1984). Total new root length is directly proportional to surface area, if, as assumed, the new roots are nearly all the same diameter. If it is further assumed that most new roots are the same length when root growth is measured after a limited period of time, such as 14 or 28 days, then number of new roots will be strongly correlated to new root length, and thus to new root surface area also. Number and length of roots are the consequence of different processes, however. Number of roots per seedling is a measure of the initiation of new roots and the initiation of renewed growth of existing roots (Stone et al. 1963). Total length of new roots produced measures both initiation and elongation (Ritchie and Dunlap 1980). Root initiation and elongation are controlled by different mechanisms (Torrey 1976), and respond differently to factors such as chilling hours (Krugman and Stone 1966), soil temperature (Nambiar et al. 1979), and nutrient status (Nambiar 1980). Thus, it should not be assumed that number and length of roots will always be strongly correlated under all RGP test conditions.

Total length and number of new roots per seedling are thought to be fairly well correlated using the standard pot test (Ritchie 1985). Total number of new roots (≧0.5 cm in length) was correlated (R=0.8667) with total length of those new roots in Pinus taeda using a 28-day pot test with an average root temperature of 26.5°C (Larsen and Boyer 1986). When RGP was measured as total number of new roots ≧1.25 cm and as total length of new roots ≧2.5 cm with a 30-day pot test and 20°C root temperatures, the two approaches gave similar results (Krugman and Stone 1966). This type of data has led to the prevalent procedure of measuring only total number of roots per seedling because of the considerable reduction in the time required to count the roots as opposed to measuring root length (Ritchie 1985). Similar information on the correlation between length and number of roots is unavailable for the aeroponic method and shorter test periods.

A seedling quality test should, ideally, provide the highest quality information, in the shortest possible time, in the most efficient manner, and for the widest range of stock types. Toward this ideal with the RGP test, the objectives of this study were to examine the quality of information provided by 7-day vs 14-day aeroponic tests of container stock from bud set to bud break, with root growth quantified as total length of new roots per seedling vs total number of new roots per seedling. This research was performed within the context of a larger study examining the relationship between root growth potential and two other seedling quality parameters: cold hardiness and bud dormancy.

MATERIALS AND METHODS

Seedlings of ponderosa pine (Pinus ponderosa var. scopulorum Engelm., Chevelon District, Apache-Sitgreaves National Forests, elev. 2,300 m), Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco, Cloudcroft District, Lincoln National Forest, elev. 2,700 m), and Engelmann spruce (Picea engelmannii (Parry) Engelm., Springerville District, Apache-Sitgreaves National Forests, elev. 3,000 m) were greenhouse-grown in 400-ml Rootrainer[3] book containers in a peat-vermiculite mix for 9 months (October 1984 - June 24, 1985). Greenhouse temperatures ranged from 23 to 28°C daily (average 25°C) and 18 to 21°C at night (average 20°C). Daylength was extended to 22 hours with fluorescent light. Other cultural conditions were as recommended by Tinus and McDonald (1979). During the ninth month, the trees set bud and entered dormancy. The seedlings were then graded and those of uniform size were placed in Percival HL-60 growth chambers for a 4-stage, 19-week cold acclimation and deacclimation regime (table 1). Sodium and multivapor arc lights provided 43,000 lux, and watering was as needed with nutrient solution. At approximately weekly intervals, a sample of 20 seedlings per species was taken for concurrent tests of cold hardiness and root growth potential.

Whole-Plant Freeze Test

Cold hardiness was measured by a whole-plant freeze test. One book of four seedlings of each

[3]Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.

Table 1.--Cold acclimation and deacclimation conditions.

Stage	Day nos.	Duration (wks)	Day temp. (°C)	Night temp. (°C)	Day length (hrs)	Nutrient Solution
1	0-21	3	20	15	10	low N, high PK
2	22-71	7	10	3	10	low N high PK
3	72-105	5	5	-3	10	low N high PK
4	106-133	4	22	22	16	high N

species was placed in each of three styrofoam coolers with the rootballs supported and covered to a depth of 5 cm with dry vermiculite. The coolers, with the lids wired shut and fitted with thermister probes into the crowns of the seedlings, were placed in a 650-liter household chest freezer. Crown temperature was lowered rapidly from ambient to 0°C and at a rate of 3 to 5°C per hour thereafter. A baking pan filled with liquid nitrogen was placed in the freezer to reach temperatures below -25°C. The pan size and degree of foam insulation controlled the rate of temperature fall. Three temperatures, 5°C apart, were selected to bracket the expected LT_{50} of the stem tissue. When a cooler reached a selected test temperature, it was removed from the freezer and placed in a refrigerator at 1°C to thaw overnight. The seedlings were then removed from the coolers and placed in a warm greenhouse (day 26°C, night 19°C, 22-hour day).

Extent of injury to each seedling was assessed after 7 days. The percentage of the length of the stem that was killed was estimated by examining the cambium and phloem for browning and loss of tissue integrity. Rates of increasing injury with decreasing temperature were compared across test day and species, and data with similar rates were subjectively placed into six groups. This pooling of data was necessary because 12 trees per species per test day did not provide adequate information for statistical analysis. Injury in the range of 10 to 90% was regressed against temperature for each group, and the 50% injury point (LT_{50}) was estimated by calibration methods (Graybill 1976). The range 10 to 90% was chosen because the relation between injury and temperature was primarily linear, but nonlinear above and below that range.

Root Growth Potential (RGP)

Eight additional seedlings per species were placed in an aeroponic mist box in a greenhouse (day 26°C, night 18°C, long days) to measure RGP. A mist box measuring 1.0 m wide x 2.4 m long x 0.6 m high, was constructed of 5 cm thick rigid urethane foam, and was fitted with a PVC piping, 3-nozzle system 25 cm above the floor of the box. The seedlings were inserted through holes in strips of plywood which formed the top of the box, and were held in place with soft urethane foam plugs. The intact rootballs, suspended within the box, were exposed to 100% relative humidity at 27°C maintained by a warm-water intermittent mist. After 7 and 14 days, the total number of new white roots, ≧0.5 cm in length, that had emerged from the rootball were measured to the nearest cm and counted. Tallied roots were marked with tempera paint to prevent duplicate measurement. (The paint was subsequently removed by the mist.) Seedling height and caliper data were also taken. Measurements were made without damage to the seedlings, which were kept in the mist chamber until bud break to assess dormancy status.

RGP was expressed as total number of new roots per seedling and total length of new roots per seedling, at 7 and 14 days. The data sets for total new root length per seedling at 14 days for the three species were selected to assess the significance of possible covariates. There was no trend over time in seedling height or caliper in any of the three species. No consistent covariance existed between RGP and height, caliper, or (height x caliper^2) in Engelmann spruce and ponderosa pine. Seedling height was a significant (p=.02) covariate in Douglas-fir, but the contribution of the covariate was so small (R^2=.04) that it did not warrant inclusion in further data analysis. There was no consistent covariance between RGP and caliper or (height x caliper^2) in Douglas-fir.

Box plots were used to flag outliers in the same three data sets (Chambers et al. 1983). Thirteen of the 360 seedlings, with RGP measurements several standard deviations from the weekly mean, were omitted after each seedling was found to be defective in some way, and therefore not properly part of the main population. Weekly means, with 95% confidence intervals, were calculated from the remaining observations for all 12 RGP data sets.

Homogeneity of variances was rejected (p≦.005) for all data sets using Bartlett's test. Welch's test was used for comparing all means within each data set because the data were not suitable for transformation. All hypotheses of equal means were rejected (p<.0001). Pairwise comparison of means with an F-protected LSD test, approximated using heterogeneous variance t-tests, resulted in many statistically significant differences (p=.05). However, because of the heterogeneous variances, detecting differences between means was not as straight forward as applying a standard least significant difference for all pairs compared. Thus, for ease of interpretation, major differences between means, as determined by the test of non-overlapping 95% confidence intervals (Jones 1984), were established and indicated on Figures 2, 3, and 4. The test of non-overlapping 95% confidence intervals was found to be intermediate between the more conservative Dunnett's T3 test (p=.05) (Dunnett 1980) and the more liberal F-protected LSD (p=.05). More importantly, the chosen method identified significant changes in RGP which could be readily envisioned as biologically important

differences. Means with 95% confidence intervals for the 12 data sets are presented in Burr (1987).

A correlation analysis between length and number was performed for both 7- and 14-day data, on an individual seedling basis within each species, to determine how well total number of new roots per seedling might indicate total length of new roots per seedling.

RESULTS

Whole-plant Freeze Test

Cold hardiness was gained and lost in response to the four successive temperature stages (fig. 1). Seedlings of the three species did not harden during the first stage with warm temperatures and short days (day 20°C, night 15°C, 10-hour day). Stem cold hardiness, expressed as an LT_{50}, ranged from -11 to -17°C for the three species during these first 21 days. When growth chamber temperatures were lowered to 10°C day and 3°C night in the second stage, there was a lag period of variable length, depending upon the species, before cold hardening of stem tissue proceeded. There was a 1-week lag (test days 21 to 28) in ponderosa pine, a 2-week lag (test days 21 to 35) in Engelmann spruce, and a 2-week lag after the first week of the second stage (test days 28 to 42) in Douglas-fir. Cold hardiness increased after these lag periods until maximum cold hardiness was reached at the end of the third stage (day 5°C, night -3°C) on test day 105.

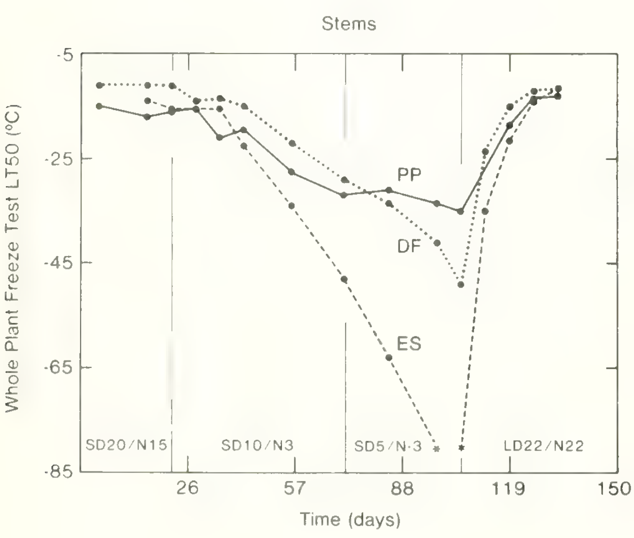


Figure 1.--Stem cold hardiness (LT_{50}) of ponderosa pine (PP), Douglas-fir (DF), and Engelmann spruce (ES) as a function of time, determined by the whole-plant freeze test. Engelmann spruce cold hardiness on test days 98 and 105 is indicated by asterisks at -80°C. On these two test days there was no injury (LT_0) to stem tissue at -75°C, the lower limit of the freezer. Growth chamber conditions are indicated across the bottom of the graph and are described in table 1.

Maximum stem cold hardiness, expressed as an LT_{50}, reached -35°C in ponderosa pine and -49°C in Douglas-fir. Engelmann spruce cold hardiness on test days 98 and 105 is indicated by asterisks at -80°C (fig. 1). On these two days there was no injury (LT_0) to stem tissue at -75°C, the lower limit of the freezer. Deacclimation began immediately in all three species upon exposure to the fourth stage conditions (day 22°C, night 22°C, 16-hour day). Cold hardiness was rapidly lost and reached minimum levels on test day 133 at the end of the 19 weeks. Stem tissue cold hardiness on test day 133 was -13°C in ponderosa pine and -11.5°C in Douglas-fir and Engelmann spruce.

Bud Dormancy

Dormancy requirements for ponderosa pine were fully met by test day 21, at the end of the first stage, and for both Douglas-fir and Engelmann spruce by test day 71, at the end of the second stage. Bud break occurred during the 18th week of the regime in Engelmann spruce, and during the 19th week in ponderosa pine and Douglas-fir.

Root Growth Potential (RGP)

The RGP patterns were similar, in a general way, for the three species, whether measured as total length or total number of new roots per seedling, after either 7 or 14 days in the mist chamber (figs. 2, 3, 4). RGP was low in the first stage when cold hardiness was at a minimum and dormancy intensity was maximum. RGP remained low for differing portions of the second stage. High, though variable, RGP levels were reached in the second and/or third stages as cold hardiness increased and chilling requirements for bud dormancy were met. Maximum RGP levels were at least 5-fold greater than minimum RGP levels. During the first week of deacclimation in the fourth stage, RGP did not decrease, although approximately 65% of maximum cold hardiness was lost. Following the first week of deacclimation, RGP declined rapidly. Both cold hardiness and RGP had returned to minimum levels at bud break.

Correlation analysis within each species indicated that total length and total number of new roots at 7 days were strongly correlated (R=.918 to .933), as were total length and total number of new roots at 14 days (R=.889 to .948) (table 2). The strength of the correlation between length and number at 7 days was similar to that at 14 days in Douglas-fir and Engelmann spruce. In ponderosa pine, the correlation between length and number was stronger at 7 days than after 14 days. The variability in total number of new roots per seedling accounted for 79.0 to 89.9% of the variability in total new root length per seedling, depending upon species and time of measurement. The patterns of the RGP means, expressed as total length and total number of new roots at each of the two measurement times, were thus very similar within each species (figs. 2, 3, 4).

In general, for the three species, changes as large or larger than a 100% increase or decrease

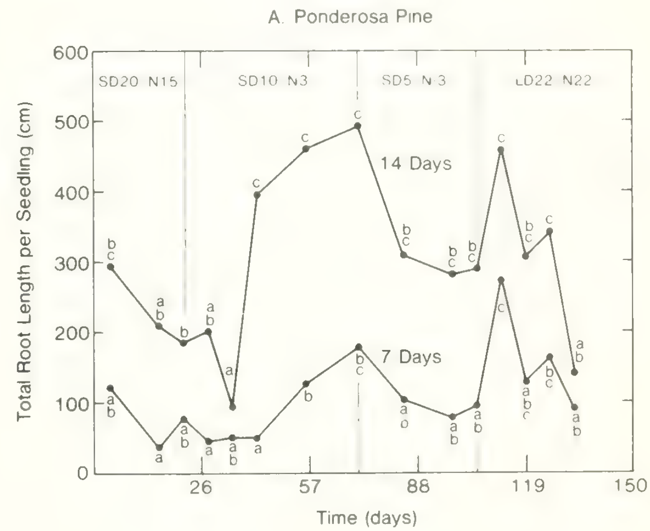
Table 2.--Correlation analysis between total length and total number of new roots per seedling for each species after 7 and 14 days in the mist chamber.

Species	R	R^2
Ponderosa pine		
7 days	.93330	.87105
14 days	.88901	.79034
Douglas-fir		
7 days	.92333	.85255
14 days	.94828	.89924
Engelmann spruce		
7 days	.91811	.84293
14 days	.90630	82138

(e.g. doubling) in RGP over time were significantly different, independent of time or method of measurement. Changes in number or length of roots during the 19-week regime were not statistically significant on the same test date when measured at 7 and 14 days. When ponderosa pine RGP was measured as total new root length per seedling (fig. 2A), the first significant increase in RGP during cold acclimation occurred on test day 42 when measured at 14 days, and on test day 56 when measured at 7 days. The decrease in RGP during the third stage was not significantly different from the peak on test day 71 when measured at either time. However, the low RGP levels in the third stage were not significantly different from the earlier low levels, such as between test days 14 and 28. RGP increased on test day 112, after 1 week of deacclimation, when measured at both times, but the increase was significant only at 7 days. RGP then returned to the original low levels. When ponderosa pine RGP was measured as total number of new roots per seedling (fig. 2B), the first significant increase in RGP during cold acclimation also occurred on test day 42 when measured at 14 days, and on test day 56 when measured at 7 days. The decrease in RGP during the third stage was significantly lower than the peak on test day 71 but also significantly greater than the earlier lowest (a) levels, when measured at both 7 and 14 days. The increase in RGP during the first week of deacclimation was significant only when measured at 7 days. RGP then returned to the original low levels.

In Douglas-fir, when RGP was measured as total length or number of new roots per seedling (figs. 3A, 3B), the first significant increase in RGP during cold acclimation occurred on test day 42 when measured at 14 days, and on test day 71 when measured at 7 days. A second significant increase occurred in both the 7- and 14-day measurements by test day 84. This was followed by a significant decrease in RGP on test day 98, when measured at 7 days, which was not significantly different from the earlier lowest (a) levels. The pattern was not the same at 14 days. The changes in RGP during the first week of deacclimation were not significant at either measurement time, and by the end of the fourth stage, RGP had returned to the earlier lowest levels.

When Engelmann spruce RGP was measured as total length or number of new roots per seedling (figs. 4A, 4B), the first significant increase during cold acclimation occurred on test day 42 when measured at 14 days, but did not occur until test day 84 when measured at 7 days. RGP fluctuated from test day 42 to the end of the third stage, on test day 105, when measured at 14 days, though none of the changes were



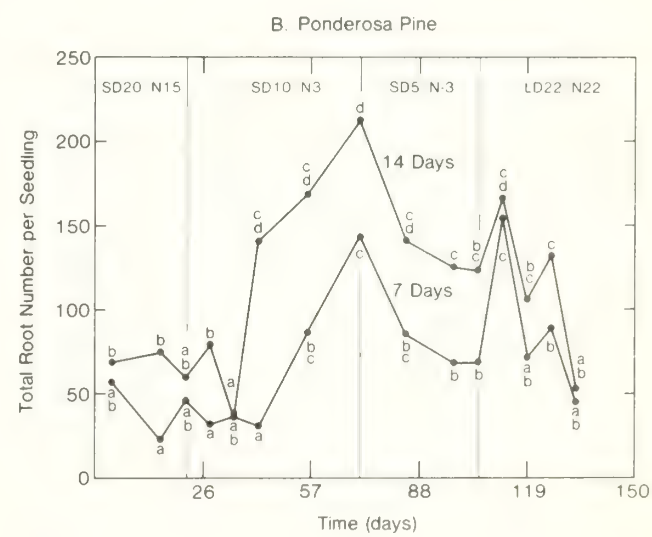


Figure 2.--Ponderosa pine root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each curve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

statistically significant. There was also no further significant change in RGP during the third stage when measured at 7 days. None of the changes in RGP during the first week of deacclimation were significant when measured after either 7 or 14 days. RGP had returned to fairly low levels at the end of the fourth stage.

Ponderosa pine data were normalized to test day 71, and Douglas-fir and Engelmann spruce data to test day 84, to illustrate the differences and similarities in the patterns of the 7- and 14-day measurements (figs. 5, 6, 7). The normalized ponderosa pine data (fig. 5) made more apparent the 2-week delay in detecting the increase in RGP during cold acclimation when RGP was measured after 7 days. Measurement of total number of new roots per seedling at 14 days best differentiated between the low RGP levels of the third stage and of the first two stages. The increase in RGP during the first week of deacclimation was readily detected when measurements were made after 7 days.

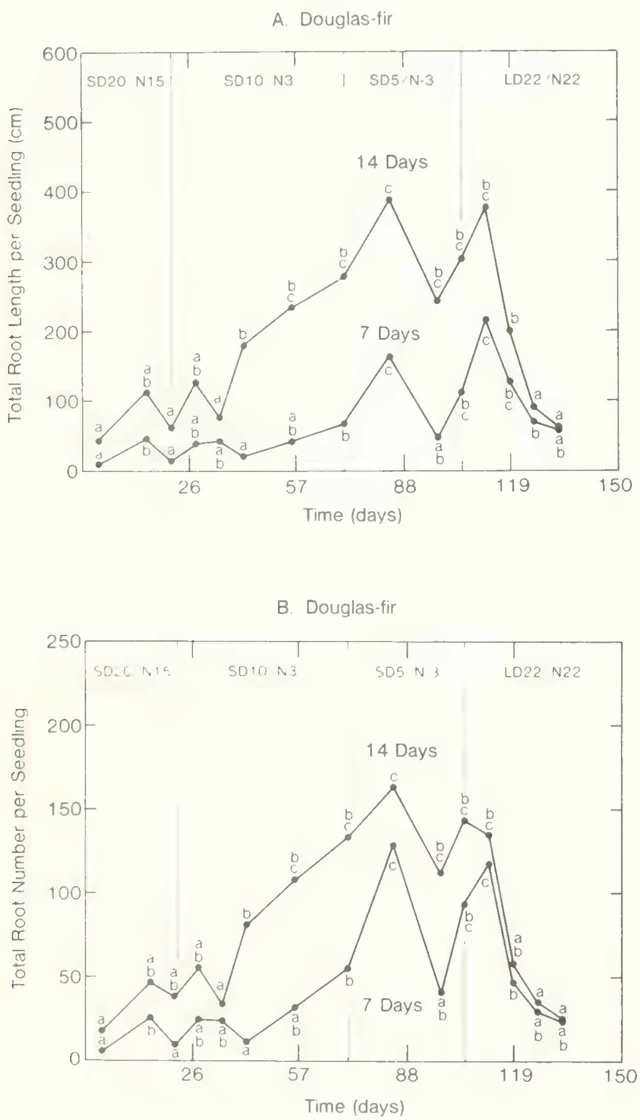


Figure 3.--Douglas-fir root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each curve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

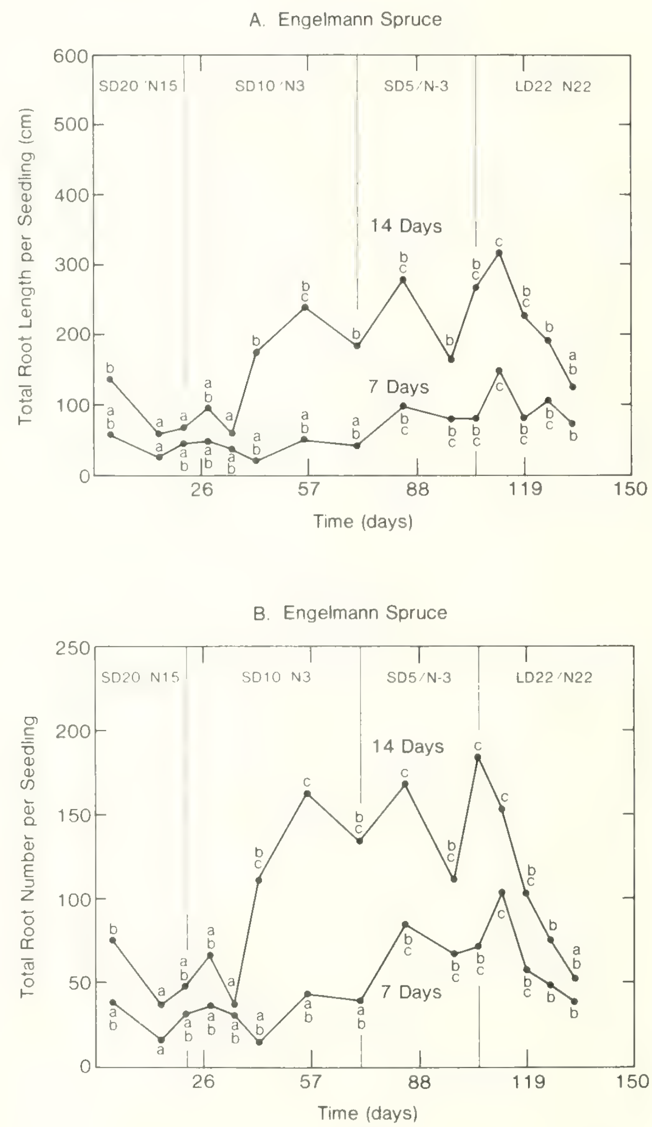


Figure 4.--Engelmann spruce root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each cruve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

The normalized Douglas-fir RGP data (fig. 6) made more apparent the 4-week delay in detecting the increase in RGP during cold acclimation when measured at 7 days. Also apparent was the inability to distinguish the low RGP on test day 98 from the RGP prior to test day 42, when measured at 7 days. When measured at 14 days, the decline on test day 98 indicated a fluctuation during a period of high RGP, rather than a sudden loss of RGP. During the first week of deacclimation, 7-day measurements suggested an increase in RGP more strongly than 14-day measurements.

Normalized Engelmann spruce RGP data (fig. 7) indicated that detection of a significant increase in RGP above the low levels prior to cold acclimation in the second stage required an additional 5 to 6 weeks when measured at 7 days. During the first week of deacclimation, 7-day measurements suggested an increase in RGP, while 14-day measurements indicated no change.

DISCUSSIONS AND CONCLUSIONS

The RGP patterns of the three species (figs. 2, 3, 4) were a function of seedling response to simulated seasonal environmental changes created in growth chambers. Nevertheless, these patterns were quite representative of RGP patterns reported in the literature for nursery-grown bareroot seedlings lifted at regular intervals from bud set to bud break (Jenkinson 1980, Ritchie and Dunlap 1980, Stone et al. 1962).

RGP's measured as total number and as total length of new roots per seedling were strongly correlated in all three species, whether measured after 7 or 14 days in the mist chamber (table 2). Number of roots was a good predictor of length, indicating that changes over time in total new root length were mainly the result of changes in the number of roots elongating rather than changes in the elongation rate of the individual roots. Rietveld (1986) found that total number (R^2=.88) and total length (R^2=.90) of new roots were strongly correlated to a root area index, using a 17-day aeroponic test. Thus, not only were number and length of new roots well correlated, but both were also good estimators of new root surface area, the parameter of primary interest. Since length and number were nearly equally informative under the test conditions used here, measuring total number of new roots is recommended because it required only 25% of the time necessary to measure total new root length. More information can thus be gained per unit of time spent in data collection by measuring only the number of new roots on a 4-fold larger sample of seedlings than by also measuring total new root length on a 75% smaller sample of seedlings. For example, using the test of non-overlapping 95% confidence intervals, a doubling of the sample size from 8 to 16 seedlings would reduce the size of the confidence interval by 35%. Since a change in RGP of approximately 100% was required to be significantly different with a sample size of 8, a 65% increase or decrease would be significantly different with a sample size of 16. A 4-fold increase in sample size from 8 to 32 would reduce the size of the confidence interval by 56% and a 44% increase or decrease in RGP would be significantly different.

A significant increase in RGP during cold acclimation was detected 2 to 6 weeks earlier in the three species when RGP was measured after 14 days, rather than after 7 days, regardless of whether root number or length was measured. The inability to detect the increase when measured at 7 days was apparently the result of low growth

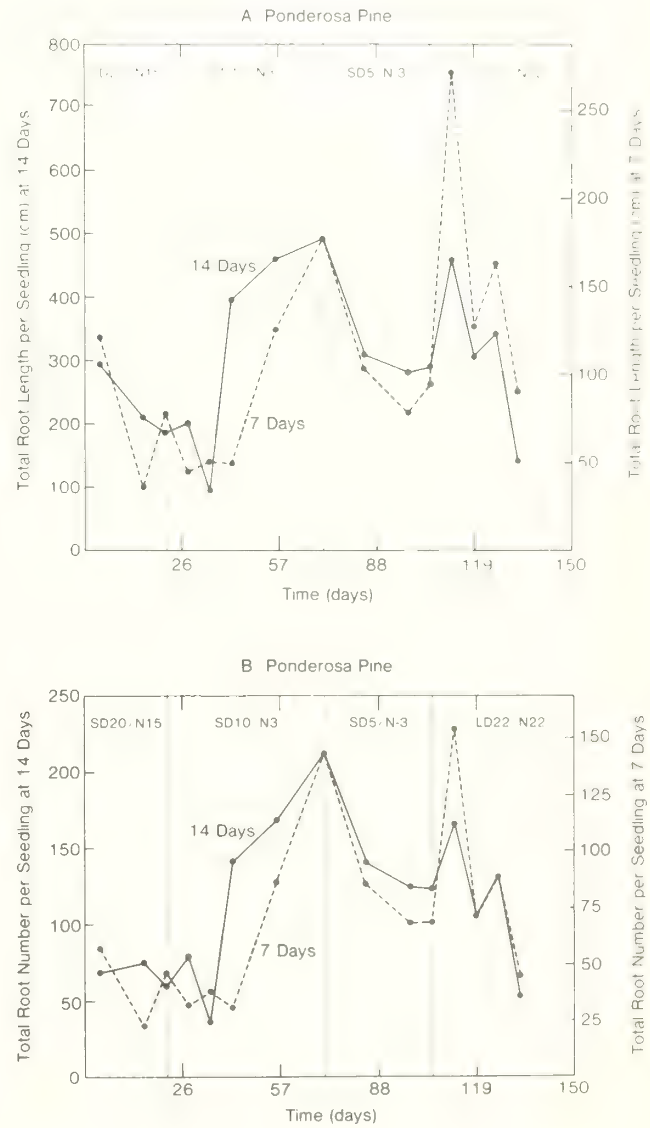


Figure 5.--Ponderosa pine root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 to 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 71. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

levels during the first 7 days in the mist chamber combined with high levels of growth during the second 7 days (figs. 2, 3, 4). A second disadvantage of 7-day measurement of RGP during the period of cold acclimation was the inability to distinguish between fluctuations in high RGP levels and the low RGP levels prior to the start of cold acclimation. This was particularly true in Douglas-fir (fig. 3) and also in ponderosa pine (fig. 2A). Additionally, all first significant increases in RGP, when measured after 14 days in the mist chamber, occurred on test day 42, whether expressed as total number or total length of new roots. The increase in RGP between test days 35 and 42 corresponded well with the onset of steady, rapid increases in cold hardiness (fig. 1). It marked the end of the plateau period at the beginning of the second stage, during which there was a lag in the development of cold hardiness as well as RGP. No such relationship was apparent between cold hardiness and RGP measured at 7 days. Measurement of RGP after 7 days was not as informative as measurement at 14 days during the period of cold acclimation for these reasons. A 7-day test of RGP prior to cold deacclimation, whether as a routine test of seedling quality or over a period of time to determine lifting windows, could be very misleading.

However, measurement of RGP after 7 days may be a better indicator of the onset of deacclimation than 14-day measurement, especially in ponderosa pine (fig. 5). For example, RGP consistently increased during the first week of

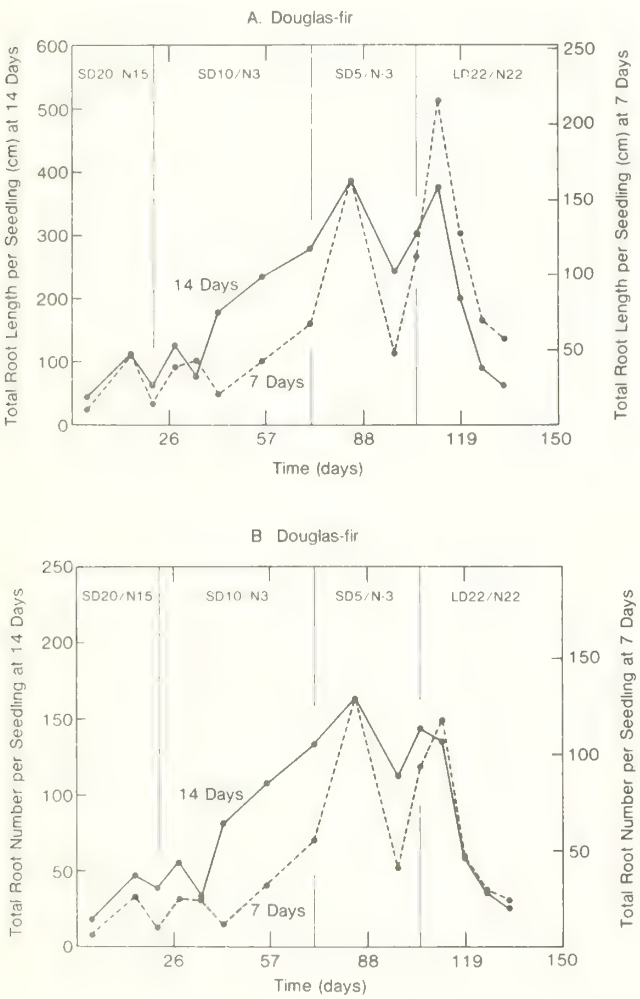


Figure 6.--Douglas-fir root growth potential expressed as (A) total length of new roots per seedling and (B) total amount of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 84. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

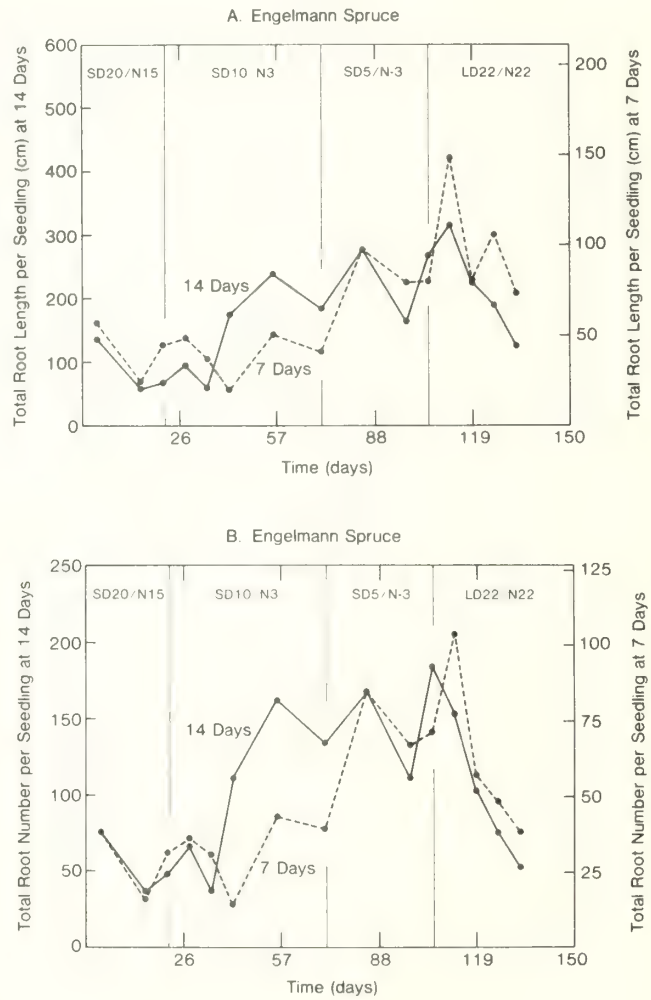


Figure 7.--Engelmann spruce root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 84. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

deacclimation when measured after 7 days. Though the increase was significant only in ponderosa pine (fig. 2), the normalized data (figs. 5, 6, 7) indicated that the relative magnitude of the increase was greater at 7 days than at 14 days in all instances. RGP measurement at 14 days during the first week of deacclimation led to the conclusion that no change occurred. The rapid decline in RGP after the first week of deacclimation was as clearly indicated in the 7-day measurements as in the 14-day measurements (figs. 5, 6, 7). This was true largely because the majority of the root growth, especially increases in number of roots, occurred during the first 7 days in the mist chamber. RGP measurements at 7 days are thus recommended if the data are to be used to monitor the rapid loss of stock quality with approaching bud break.

In summary, total length and total number of new roots per seedling were nearly equally informative with container stock under the mist chamber conditions described. Use of number of roots with relatively larger sample sizes is recommended as most efficient and informative. RGP tests of 7 and 14 days in duration yielded different information. On the basis of accuracy and quantity of information provided, the 14-day test is recommended during cold acclimation and the 7-day test is suggested for use during cold deacclimation.

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Effects of Lift Date, Storage, and Family on Early Survival and Root Growth Potential of Shortleaf Pine[1]

S. W. Hallgren and C. G. Tauer[2]

Abstract.--High survival and RGP can be expected for seedlings planted from December through February even when a severe spring drought occurs. Seedling performance is only slightly reduced by storage, is positively related to number of primary lateral roots, negatively related to presence of secondary needles, and not related to the presence of a terminal bud.

INTRODUCTION

Shortleaf pine (Pinus echinata Mill.) is the most widespread of the southern pines. It is an important timber species, and is widely planted by the U.S. Forest Service and private industry. Current nursery practices and regeneration techniques that work well for loblolly pine are apparently inappropriate for shortleaf pine which shows very poor survival in plantations in the Ozark and Ouachita Mountains. Contributing to these poor results is the lack of specific information about artificial regeneration of shortleaf pine (Barnett et al. 1986).

Previous research has led to the recommendation that southern pine seedling quality be assessed by grading seedlings for planting. Results vary somewhat, but in general best performance can be expected from seedlings that are large and have an appropriate root/shoot ratio, that have a woody stem, secondary needles and a terminal bud (Wakely 1954, Phares et al. 1960, Grigsby 1975, Barnett 1984, Barnett et al. 1985). Shortleaf pine seedlings grown in southwest Arkansas showed high field survival when lifted and planted immediately during December through February. Only seedlings lifted in December retained high survival rates after cold storage for 30 days (Venator 1985).

The capacity of a seedling to rapidly produce new roots when transplanted into the field is critical for survival and growth. A frequently used measure of this capacity is root growth potential (RGP) which is considered a valuable tool for assessing seedling quality (Ritchie and Dunlap 1980). RGP can be measured by growing seedlings in a controlled environment for 4 weeks and counting the number of new roots greater than 1 cm long. Factors known to affect RGP are genotype, nursery environment, lifting dates, and storage (Ritchie and Dunlap 1980, Jenkinson and Nelson 1978, Carlson 1985), but very little is known about RGP in shortleaf pine.

This study was undertaken to develop improved techniques for artificial regeneration of shortleaf pine. Since there is considerable interest in managing seedlings by family we decided to evaluate the genetic variability in effects of lift date and storage on survival and growth. In order to better understand treatment response, seedlings were also measured for size, number of primary lateral roots, root growth potential and presence of secondary needles and a terminal bud.

MATERIALS AND METHODS

Shortleaf pine seedlings of 12 open-pollinated families from Oklahoma and Arkansas were grown for one season under operational procedures at the Weyerhauser Company Nursery at Fort Towson, Oklahoma. Seedlings were grown in 3 replicates in a randomized complete block design. They were operationally undercut at a depth of 15 cm in November 1986.

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Starting December 1, 1986, one fifth of the seedlings in each replicate were hand-lifted every 28 days for 5 lifts until March 23, 1987 (Table 1).

Table 1.--Schedule of Lift and Plant Activities

Lift	Not Stored	Plant Stored
Dec. 1	Dec. 2	
Dec. 29	Dec. 30	Dec. 30
Jan. 26	Jan. 27	Jan. 27
Feb. 23	Feb. 24	Feb. 24
Mar. 23	Mar. 24	Mar. 24
		Apr. 21

Following each lift seedlings were graded according to operational standards and divided into two equal groups, one for immediate testing and one to be stored for 28 days and then tested. Each group was divided a second time, 80 seedlings per family going to the field planting and 24 to the RGP test. The integrity of nursery replicates was maintained throughout the study.

The field test was planted at the Kiamichi Forest Research Station near Idabel, Oklahoma. Seedlings were planted one day after lifting or upon removal from 28 days of storage. The experimental design was a 12 x 5 x 2 (family x lift date x storage) factorial with 10 replicates laid out in randomized complete block design. Each treatment combination was represented by an 8-tree row plot in each replicate. A total of 9600 trees were planted at a spacing of 0.5 m and the entire experiment was surrounded by a border row of similar shortleaf pine seedlings. Immediately after the last planting, all the seedlings were measured for survival, diameter and height.

Weeds were controlled by herbicides and manual methods. No irrigation was applied. Temperature and precipitation were monitored at a weather station on the center. Early survival was counted on June 22, 1987. The experiment will be monitored for survival and growth for two years.

Seedlings for the RGP test were kept in cold storage until the test began 3 days after lifting or the end of the cold storage treatment. Prior to commencement of the RGP test seedlings were measured for height, diameter, number of primary lateral roots, root volume and presence of secondary needles and a terminal bud.

Three seedlings of a family were planted into 1 l milk carton pots filled with a 1:1 peat-vermiculite mixture (on the first test date, 2 l cartons were used). The pots were arranged in a randomized complete block design with 8 replicates. The test was conducted in a controlled environment chamber set for a 16 hour photoperiod and a 25^{o} C day/15^{o} C night. After 28 days the seedlings were removed from the chamber and placed in cold storage until the roots could be washed and the new root tips longer than 1 cm counted. RGP measurement was complete within 2 to 3 days.

The data were subjected to analysis of variance to determine the significance of family, lift date and storage on RGP and seedling survival. Phenotypic correlations between survival and the various seedling traits were calculated.

RESULTS AND DISCUSSION

Lift date, storage and family all showed a significant effect (P< 0.05) on survival and RGP of shortleaf pine (Table 2).

Table 2.--Analysis of Variance Results

		Probability > F	
Source	DF	Survival	RGP
Date (D)	4	<0.0001	<0.0001
Storage (S)	1	<0.0001	0.0465
Family (F)	11	<0.0001	<0.0001
D x S	4	<0.0001	<0.0001
D x F	44	0.2765	<0.0001
S x F	11	0.7704	0.4405
D x S x F	44	0.0323	0.2512
Error	1071/833		

A significant interaction of lift date with storage suggested that seedling performance after storage is dependent in part on lifting date. The lack of an interaction between family and lift date and family and storage treatment for survival indicates that in general the families respond in a similar manner to lift date and storage. However, a significant three-way interaction between lift date, family and storage treatment suggests the survival response is complex. In general, the families showed a dissimilar RGP response to different lift dates but a similar RGP response to storage treatment.

These results correspond well with previous work in pines that has shown lift date to affect survival and RGP (Jenkinson 1975, Jenkinson and Nelson 1978). Lift date is also known to determine the response of seedlings to storage (Stone and Jenkinson 1971, Venator 1985). The pattern of changes in RGP and survival with time of lift as well as the magnitude of RGP at a given date have been shown to be under strong genetic control (Jenkinson 1975, Nambiar 1982, Carlson 1985 and 1986).

Overall, survival was high, over 90 percent, for seedlings planted from early December to late February whether they were stored or not (Figure 1). Survival fell after February and the late March planting showed survival of 80 and 85 percent for freshly lifted and stored seedlings. Only stored seedlings were planted in late April and survival was poor, less than 50 percent.

Survival for a specific planting date was generally reduced only 5 percent by storage (Figure 1). Seedlings lifted on a given date showed a reduction in survival due to storage of only 2 percent in December, 8 to 10 percent in January and February and 36 percent in March. The March lifted seedlings planted in April showed poor survival partly due to the spring drought.

RGP followed a seasonal pattern somewhat similar to that for survival, showing high values of 80 to 110 new roots for seedlings lifted in December, stored and unstored, and in January, unstored (Figure 2). RGP fell to 50 to 75 new roots for stored seedlings lifted in January and all seedlings lifted after January whether stored or unstored. The stored seedlings tested in April showed a higher RGP than seedlings tested in March and yet they showed much lower survival in

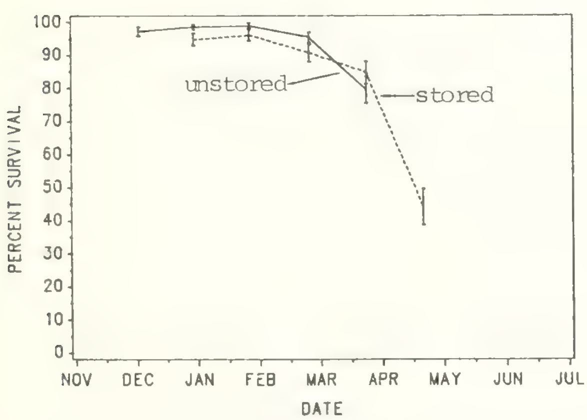

Figure 1. Effect of lift date and storage on June 22 survival of shortleaf pine seedlings by planting date. Points represent values averaged across 12 families and bars represent plus and minus the standard error of the mean.

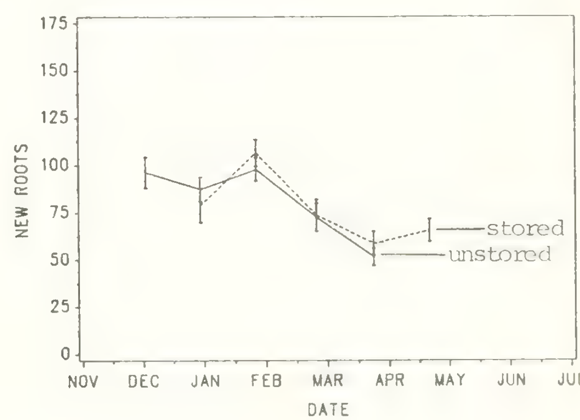

Figure 2. Effect of lift date and storage on root growth potential of shortleaf pine seedlings by date tested. Points represent values averaged across 12 families and bars represent plus and minus the standard error of the mean.

The late season drop in survival can be at least partially explained by the weather at the planting site. Temperatures were mild and precipitation adequate from November 1986 through March 1987. The weekly maximum temperatures never exceeded 30^{o}C and monthly rainfall ranged from 45 mm in December to 164 mm in March. April and early May were much hotter and drier with weekly maximum temperatures constantly above 33^{o}C and rainfall of only 9 mm from March 30 until May 15. Temperatures remained high and precipitation returned to higher levels for the last 2 weeks of May (154 mm) and the first 3 weeks of June (40 mm).

the field. Apparently the higher RGP did not prevent severe mortality for seedlings planted in the middle of the spring drought. It is worth noting that in general RGP declined for seedlings lifted in February and later at the same time that risk of mortality from drought and high temperature was increasing. The effects of storage on RGP were generally small and inconsistent from one lift date to the next.

Comparison of survival across all dates for families showing the highest (Family 5) and lowest (Family 6) survival reveals small differences for unstored

seedlings, usually less than 10 percent, and much larger differences for stored seedlings, usually 20 percent or greater (Figure 3). These families showed similar seasonal changes in survival and maintained their respective ranks regardless of storage treatment.

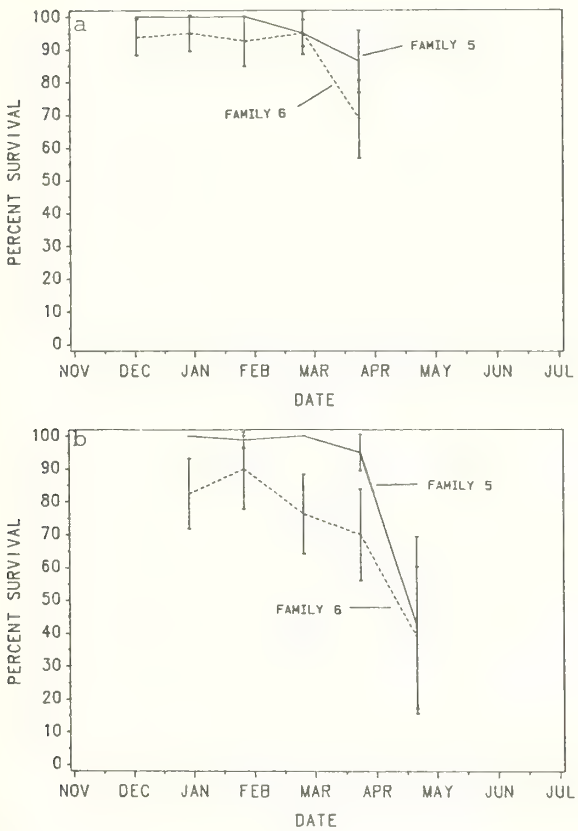

Figure 3. Effect of lift date and storage on June 22 survival of shortleaf pine families showing the highest (Family 5) and lowest (Family 6) overall survival. Data are plotted by date planted for unstored (a) and stored (b) seedlings. Bars represent plus and minus the standard error of the mean.

RGP showed a good relationship to field survival, as high survival for Family 5 was associated with high RGP and low survival of Family 6 was associated with low RGP across all dates regardless of storage treatment (Figure 4). Unstored seedlings showed a peak RGP in early December for Family 5 and late January for Family 6. Stored seedlings showed a peak RGP for both families in late January.

Survival was significantly correlated to RGP and number of primary lateral roots

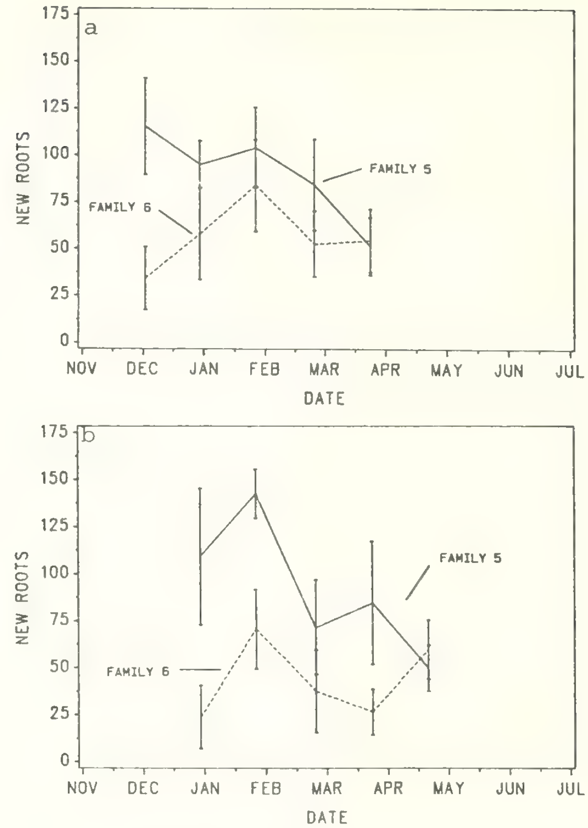

Figure 4. Effect of lift date and storage on root growth potential of shortleaf pine families showing highest (Family 5) and lowest (Family 6) overall survival. Data are plotted by date tested for unstored (a) and stored (b) seedlings. Bars represent plus and minus the standard error of the mean.

(Table 3). Previous research has often shown a close relationship between RGP and survival (Ritchie and Dunlap 1980, Nambiar et al. 1982, Larsen et al. 1986). Other root characteristics such as root weight and shoot/root ratio may be correlated with survival (Larsen et al. 1986), and the importance of primary laterals in development of RGP has been noted (Nambiar et al. 1982). The current study clearly shows the close relation between number of primary laterals and survival. In fact, it was a better predictor of survival than RGP. Number of primary laterals is easier to measure than RGP and should be given consideration as a measure of seedling quality.

Survival showed no correlation with root volume, diameter and height (Table 3). We observed that root volume appeared to be largely determined by the tap root size which was reflected in seedling diameter, hence the close relation between

Table 3.--Phenotypic Correlations for Survival and Various Seedling Traits

	RGP	ROOT	ROOT VOL.	DIA	HGT	BUD	SECONDARY NEEDLES
SURVIVAL	.657*	.709*	.109	-.173	-.093	-.263	-.661*
RGP		.900**	.527	.216	.126	-.268	-.299
ROOT			.624*	.290	.223	-.140	-.278
ROOT VOL.				.842**	.327	.353	.384
DIA.					.614*	.600*	.620*
HEIGHT						.384	.246
BUD							.707**

* Significant at 5% level
**Significant at 1% level

root volume and diameter. Apparently, the number of primary lateral roots is more important in determining survival than tap root size.

Surprising was the fact that survival was not related to the presence of a bud and was negatively related to the presence of secondary needles. The presence of both a terminal bud and secondary needles has been suggested as important to seedling quality (Wakely 1954, Barnett et al. 1986). The data from this study indicates that this recommendation should be reevaluated, at least for shortleaf pine. Very little attention has been paid to this species and it appears that regeneration techniques developed for other southern pines are not well suited to it.

RGP was, not surprisingly, strongly correlated to number of primary lateral roots. This again reinforces the suggestion that number of primary laterals be considered as a measure of seedling quality. RGP was not related to any of the other seedling traits.

CONCLUSIONS

Early results show survival is high for seedlings lifted from early December through the end of February and planted without storage. Seedlings lifted in December and January can be stored for 28 days with only a slight reduction in survival. Seedlings planted in March and April are subject to greater mortality. High RGP and number of primary lateral roots are associated with high survival. The presence of a terminal bud shows no relation to survival, and the presence of secondary needles appears to be negatively related to survival. Family differences in performance indicate a significant opportunity to improve regeneration techniques through management of seedlings by family.

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Fall Lifting: Its Effects on Dormancy Intensity of Ponderosa Pine Seedlings — A Preliminary Investigation[1]

Steven K. Omi and Ursula K. Schuch[2]

Abstract.--Initial assessment of the feasibility of fall lifting ponderosa pine seedlings at Bend Pine Nursery, Oregon, involved calculating fall chilling hours and monitoring release of seedlings from dormancy. Seedlings lifted earliest failed to break bud, whereas budbreak was accelerated for trees lifted later in the fall. Results suggest that chilling was required to release seedlings from dormancy.

INTRODUCTION

Three basic lifting practices are available for use in high elevation or latitude nurseries: (Option 1) fall lift and plant, (Option 2) late winter or spring lift and plant, and (Option 3) fall lift, overwinter storage, and plant. Disadvantages of Option 1 include risks that early fall snows or drought will terminate the planting operation (Tung et al. 1986) and that stock will be lifted before it is physiologically ready (Ritchie et al. 1985). Fall lifting date is critical because of the potential to upset natural phases of dormancy and release of seedlings from dormancy.

A disadvantage of Option 2, the most common practice in the Northwest, is that nursery soils may remain frozen in the spring when sites are ready for planting. In addition, seedlings left in the ground during winter months may be exposed to desiccating conditions and may be sensitive to physiological stress at the end of the safe lifting window (Ritchie and Dunlap 1980, Ritchie et al. 1985).

Disadvantages of Option 3 include that of Option 1 regarding fall lifting date. Furthermore, storage can be unsuccessful if seedlings are lifted prior to the period of deep dormancy, when buds are not responsive to chilling (Stone and Schubert 1959, Ritchie and Dunlap 1980). Seedlings which are not at their fully dormant stage have higher respiration rates (Hocking and Ward 1972, Navratil 1973) and may deplete their reserves faster during storage than do fully dormant seedlings. Use of Option 3 has been discouraged in the past (Hocking and Nyland 1971, Hermann et al. 1972, Navratil 1973), based on data primarily derived from research on mid- or low-elevation conifer species (Tung et al. 1986). Recent studies, however, indicate that fall lifting and long-term cold storage of high elevation or latitude stock are feasible (Ritchie et al. 1985, Tung et al. 1986).

Fall lifting and overwinter storage ensure that stock is available when sites are ready for planting. This practice alleviates winter losses due to rodents, desiccating winds, or extreme temperatures (Hocking and Nyland 1971). In addition, it allows greater flexibility in the workload and makes nursery areas available for early cultivation (Hocking and Ward 1972, Mullin and Bunting 1972, Hinesley 1982). Low temperature storage of seedlings also can play a role in satisfying chilling requirements (van den Driessche 1977, Ritchie et al. 1985). The relationship among lifting date, chilling hours, and dormancy intensity for ponderosa pine is not well known.

Bend Pine Nursery (Bend, Oreg.) is located at an elevation of 3700 ft (1100 m), where soils can remain frozen in spring when lower elevation forest sites are ready to plant. Fall lifting has not been attempted recently at this nursery; however, the practice of fall lifting and overwinter storage is used for a variety of conifer species at three USDA Forest Service nurseries in the Northwest/Intermountain

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region--Wind River Nursery (Carson, Wash.), Lucky Peak Nursery (Boise, Idaho), and Couer d'Alene Nursery (Idaho). These nurseries are similar to Bend Pine Nursery in that their operations are subject to winter snows and frozen soils.

A preliminary trial was initiated in fall 1986 to assess the feasibility of fall lifting at Bend Pine Nursery. The objectives of the investigation were to determine (1) the dormancy status of fall-lifted trees and the preferred chilling range for release of seedlings from dormancy, and (2) the relationship between cumulative chilling hours and budbreak.

METHODS

Two-year old seedlings from three seed sources (courtesy of Warm Springs Indian Reservation in central Oregon--seedlots 38-85112 [3000 ft], 38-85110 [3500 ft], and 38-85105 [4000 ft]) were selected for study. These seed sources were chosen because seedlings could be destined for sites which are plantable prior to the average spring thaw in the nursery--a situation in which fall lifting and overwinter storage could be advantageous. Seedlings were shovel-lifted on three dates (October 22, November 5, and November 13, 1986) from four replications of each seed source. An additional lift of seedlings from seed source 3500 ft was made on February 19, 1987. Immediately after lifting, seedlings were packed in ice, transported to Corvallis, Oreg., and placed in cold dark storage (2°C) for approximately 12 h. Seedlings from each replication then were potted (10 seedlings per pot, 4 pots per seed source) in a 1:1:1:2 soil:sand:peat:pumice mixture and placed in a glasshouse with a 13-h extended photoperiod supplemented with lighting from 300-watt incandescent bulbs. Daily maximum and minimum temperatures were approximately 24°C and 12°C, respectively. Soil moisture was maintained near saturation.

Dormancy intensity was determined by scoring each seedling for terminal budbreak (separation of bud scales to reveal emerging needles) and tallying percent budbreak for each pot of 10 seedlings. Seedlings were monitored for 20 wk after each 1986 lift date; the 1987 lift was assessed for 7 wk.

Sensors at the nursery weather station took a temperature reading every 5 min and recorded hourly averages. Cumulative chilling hours were determined by summing the number of hours that the average hourly temperature was within a given range. Temperature ranges were defined as: (1) less than or equal to 5°C (41°F), (2) 0-5°C, (3) less than or equal to 10°C (50°F), and (4) 0-10°C. The starting date for accumulation of chilling hours was set arbitrarily as September 10. Chilling hours were calculated for three sensor locations from September 10, 1986 to February 19, 1987.

To quantify the relationship between chilling hours and budbreak, percent budbreak for each seed source after 20 wk was plotted against cumulative chilling hours. Examination of residual plots after fitting linear relationships, lack of fit tests, and tests for nonconstant error variance (Weisberg 1985) suggested that linear models were not appropriate for the untransformed data. An arcsine square root transformation of the budbreak proportions was found to linearize the relationship and stabilize the variance for seed sources 3000 and 4000 ft; a quadratic term was required for fitting the regression equation for seed source 3500 ft.

RESULTS

Chilling hours generally started to accumulate during September, and increased later in the fall, regardless of chilling temperature range (fig. 1). However, as indicated in

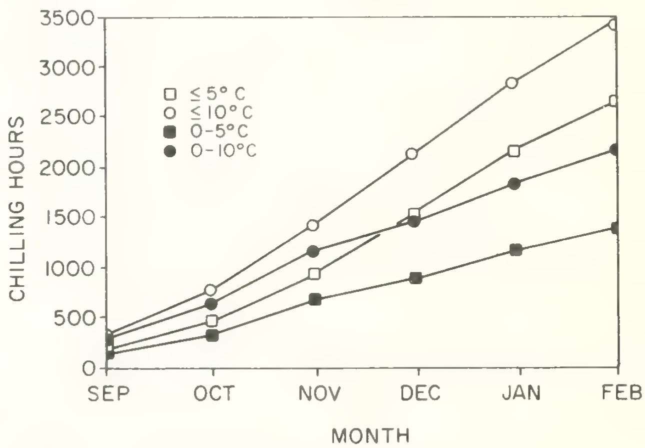

Figure 1.--Cumulative chilling hours from September 10, 1986 to February 19, 1987 at 20 cm above the surface for four temperature ranges.

figure 1, cumulative chilling hours differed, depending on the temperature range defined. For example, cumulative chilling hours in February differed nearly threefold between the temperature range less than or equal to 10°C and that from 0 to 5°C.

As expected, the later the lift date, the more chilling hours the seedlings received (table 1). Chilling hour data (temperature range less than or equal to 5°C) for the sensor 20 cm above ground surface indicated that the first three lift dates differed by over 100 h each (table 1). More than 2400 chilling hours were received by seedlings lifted February 19.

Percent budbreak was similar for all three seed sources (fig. 2). Budbreak in the glasshouse environment was virtually nonexistent for trees lifted October 22; no budbreak occurred

in seedlings from seed sources 3000 and 4000 ft. Slightly more activity (8-13 percent budbreak after 5 mo) occurred in seedlings lifted November 5, and the percentage of seedlings which flushed after 12, 16, and 20 wk increased consistently for all seed sources lifted November 13. Budbreak was especially accelerated for seedlings (seed source 3500 ft) lifted February 19 (fig. 3). These trees achieved the same amount of budbreak after 6-7 wk as the trees lifted on November 13 did after 20 wk.

In an attempt to determine a preferred chilling range for releasing ponderosa pine seedlings from dormancy, percent budbreak after 20 wk was plotted against cumulative chilling hours for the four temperature ranges studied. Similar to findings of Ritchie et al. (1985), all chilling ranges exhibited similar patterns and none was clearly advantageous. Therefore, the range less than or equal to 5°C was utilized for remaining analyses because of its practical use in tallying chilling hours in some Northwest nurseries (Ritchie et al. 1985).

The relationship between budbreak proportion after 20 wk (transformed) and cumulative chilling hours was linear for the 3000 and 4000 ft seed sources. Regression equations derived from data on these seed sources did not differ statistically ($p > .05$); therefore, data were combined to produce a single linear regression model (fig. 4, budbreak = -1.074 + .003 [chilling hours]). Differences in chilling hours accounted for 74 percent of the variation in budbreak for

Table 1. Chilling hours accumulated from September 10, 1986 to four 1986-1987 lifting dates at three sensor locations for four temperature ranges.

		Chilling hours accumulated			
	Sensor location	Temperature ranges			
Time period	above ground	$\leq$5°C	0-5°C	$\leq$10°	0-10°C
Sept 10-Oct 22	1.5 m	322	278	666	622
	20 cm	396	290	644	538
	surface	205	195	533	523
Sept 10-Nov 5	1.5 m	443	382	884	823
	20 cm	533	391	856	714
	surface	337	327	737	727
Sept 10-Nov 13	1.5 m	599	477	1065	943
	20 cm	683	472	1029	818
	surface	474	441	908	875
Sept 10-Feb 19[1]	1.5 m	2459	1466	3336	2343
	20 cm	2478	1369	3238	2129
	surface	2551	1863	3210	2522

[1]Information from 4:00 p.m. December 8 to 11:00 a.m. December 9 not available.

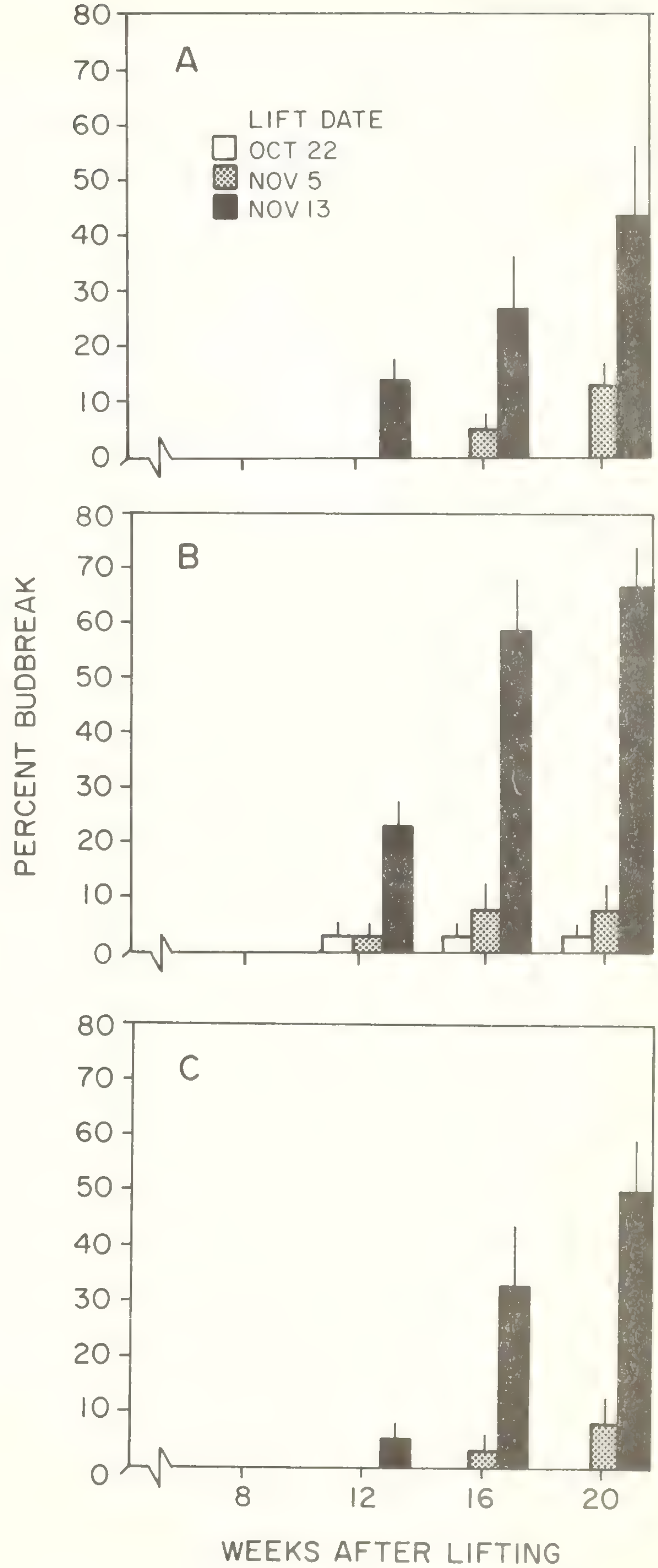

Figure 2.--Percent budbreak ($\pm$ SE) for seedlings from seed sources (A) 3000 ft, (B) 3500 ft, and (C) 4000 ft assessed for 20 wk after three lifting dates.

these two seed sources (n = 24). A curvilinear relationship existed for seed source 3500 ft (n = 12), with a coefficient of determination equal to .85 (fig. 4, budbreak = 2.874 - .013 [chilling hours] + .00001 [chilling hours]^2).

DISCUSSION

The number of chilling hours required for growth to resume following dormancy has been estimated at 1200 h at 0-10°C or 1400 h below 5°C for Douglas-fir (Ritchie and Dunlap 1980). Such information for ponderosa pine is lacking. With the assumption that differences in budbreak between lifting dates were due to differences in cumulative chilling hours, the results of this trial suggest that seedlings from the tested seedlots had a chilling requirement. Seedlings in the greenhouse were never exposed to long photoperiods (e.g., 16 h), which can compensate partially for inadequate chilling (Campbell and Sugano 1975). Apparently, seedlings were in deep dormancy during the early fall lift, and may have been unable to resume growth because they needed chilling hours (Perry 1971). Thus, seedlings could have been released from dormancy with the accumulation of chilling hours (e.g., Lavender 1985).

In contrast to the findings of this trial, Tinus et al. (1986) reported no chilling requirement for ponderosa pine. They used a high elevation (7000 ft) Arizona seed source and raised seedlings in containers under greenhouse conditions.

Chilling hour data were retrieved from the weather station with only minor problems. Installed recently (June 1986) for the USDA Forest Service Reforestation Improvement Program (see Rietveld, this proceedings), the weather station immediately showed its potential use in collecting beneficial information for the nursery. Nonetheless, determination of chilling requirements poses numerous problems. Not all chilling temperature hours below a specified quantity are equally effective in releasing seedlings from dormancy (Ritchie et al. 1985). In addition, the chilling period may be interrupted by warm temperatures. The relationship between chilling hours and release of seedlings from dormancy under controlled environments will be more intensively studied during fall 1987. In addition, investigations of the interaction between dormancy intensity of fall-lifted trees and the ability to tolerate long-term storage, as well as of effects of fall lifting and long-term storage on seedling carbohydrates and outplanting performance, are planned for 1987.

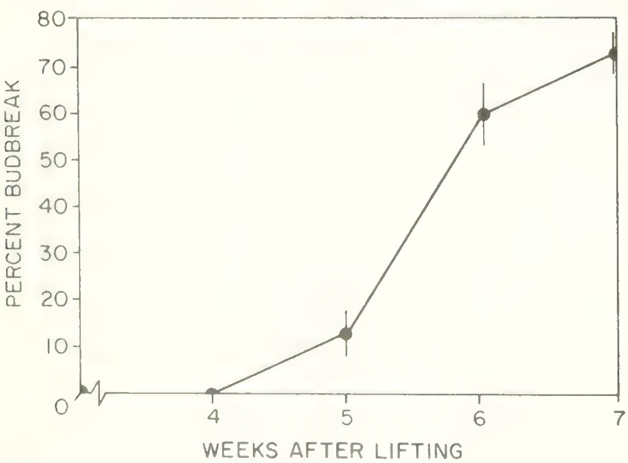

Figure 3.--Percent budbreak (± SE) for seedlings from seed source 3500 ft assessed for seven weeks after lifting February 19, 1987.

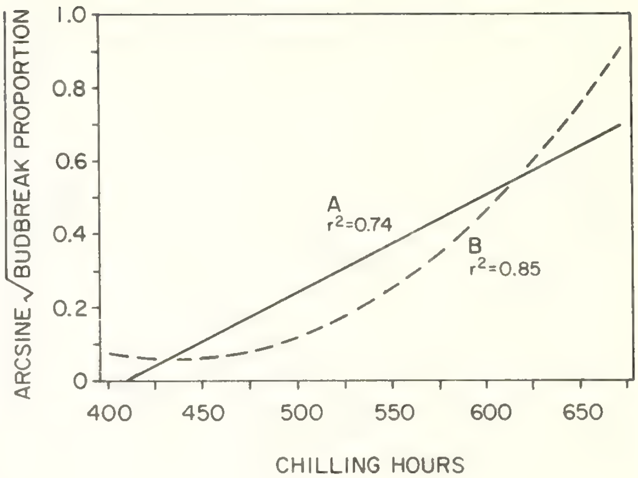

Figure 4.--Relationship between budbreak proportion (transformed) and chilling hours for seed sources (A) 3000 and 4000 ft, and (B) 3500 ft.

ACKNOWLEDGEMENTS

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A Status Report on Nursery and Reforestation Projects at the Missoula Technology and Development Center[1]

Ben J. Lowman[2]

Abstract.--This paper presents an overview of work underway in the nursery and reforestation program at the Missoula Technology and Development Center. Projects include the Seedling Counter, Seeders, Seedling Handling Equipment, Root Regeneration Chambers, a Stake Driver, an Improved Planting Auger, and Field Storage.

INTRODUCTION

The Missoula Technology and Development Center (MTDC) has a long history of development in nursery and reforestation work. Current projects at MTDC are indicative of a continued commitment to improve Forest Service reforestation and nursery programs. The status of current projects follows:

Nursery Technical Services.--Our goal in this project is to provide engineering assistance to Forest Service nurseries and to disseminate information to help nursery managers keep current with technological advances. Under this project, we maintain drawing files on nursery equipment and send them to nursery managers and others on request. In FY 1987 MTDC built 14 Root Growth Chambers and drawings were prepared based on Dr. Tinus and Dr. Reinfelt's design. In addition, electrical protection was provided for 44 weather stations associated with the Reforestation Improvement Program. Detailed construction plans for two sizes and types of Root Growth Chambers are available on request.

Seedling Counter.--Forest Service nursery managers must have an accurate and current count of their seedling crop by age and seedlot for inventory, planning, and scheduling. Our goal is to provide a fast, accurate, and inexpensive system for counting seedlings in the nurserybed. After analyzing current technology, Center engineers decided that an optical-electrical approach was the most feasible. A contract was awarded to Dr. Glenn Kranzler at Oklahoma State University to continue his work on seedling counting. Dr. Kranzler performed laboratory tests that provided information Center engineers used to design a prototype counting system. The counting system uses laser beams with linear array detectors and light emmitting diodes with linear array detectors. Preliminary tests at Lucky Peak Nursery in Boise, Idaho, showed promise. Further tests and refinements of the counter will continue in 1988.

Seeders.--Uniformly spaced seed in the nurserybed helps determine the quality of stock produced. Nursery managers need a precision seeder to accomplish this. MTDC continues to monitor industry to determine the state-of-the-art in precision seeders. We are particularly interested in high speed transplanting equipment used in row crops. In 1988, Center engineers will conduct lab tests on at least two precision seeders to determine their applicability for sowing longleaf pine seed. MTDC engineers will also design, fabricate, and test an improved hand seeder for sowing small progeny seed lots.

Seedling Handling Equipment.--As the direct result of a survey of Federal nursery managers, MTDC designed, fabricated, and tested a prototype box pickup and conveyor system for moving tubs full of trees from the ground to a trailer for transporting to the packing shed. Design, fabrication, and initial testing will be completed by the end of 1987. Information and drawings of this system will be available in the spring of 1988.

Stake Driver--A three-point hitch-mounted stake driver was designed, built, and transported to Bend Pine Nursery for use in installing netting that protects seeds from birds. This stake driver was used in the spring of 1987 with excellent success. Drawings are available.

Improved Planting Auger.--The Intermountain Forest and Range Experiment Station experimented with varying the shape of planting holes to improve seedling establishment and growth. They found that cone-shaped holes appear best suited for bareroot seedlings. MTDC was asked to design and build several styles of cone-shaped augers for evaluation. Six prototype augers were built and evaluated in the Intermountain and Pacific Northwest Regions. Personnel selected a prototype design that creates a 4-inch diameter hole. Its bottom 6 inches is tapered to about 1 inch. Ten of these augers are being field tested. MTDC will refine the augers in 1988.

Field Storage.--The nursery manager must protect seedlings from injury and damage from the time they emerge until they reach their shipping destination. Nursery managers usually have the equipment, materials, and trained personnel to provide the necessary protection, but field units that take possession of the planting stock often cannot provide protection. Portable pick-up sized cold transport units are needed. In FY 1987, center personnel contacted field units to define the requirements for such transport and storage units. One manufacturer sent a proposal for a unit using the truck 12-volt system, batteries, solar panels, and eutectic cold plates for refrigeration. The proposal has been sent to 15 field units for their comments. MTDC will analyze these comments and base further work on the results of this analysis.

Grading Pine Seedlings with Machine Vision[1]

Glenn A. Kranzler and Michael P. Rigney[2]

A machine vision technique for grading pine seedlings at production line rates was developed. Singulated seedlings were inspected on a moving belt. Classification as acceptable or cull was based on minimum criteria for stem diameter, shoot height, and projected root area. Individual seedlings were graded in approximately 0.25 seconds. Average classification error rate was 5.7 percent.

INTRODUCTION

Hundreds of millions of tree seedlings are grown each year in commercial, federal, and state nurseries. At harvest, these bare-root seedlings are graded to remove inferior stock and improve productive potential.

Grading is typically performed manually by grasping individual seedlings from a conveyor belt and applying a number of visual quality criteria. Manual inspection tends to be labor-intensive and costly. Seedling classification is subjective and susceptible to human error. Grading into more than two classes is not feasible. Valuable production data such as seedling count and classification statistics are difficult to obtain. Disadvantages of manual grading have spurred growing interest in automated alternatives.

A seedling grading machine was commercially tested by Lawyer (1981). This mechanical system measured stem diameter, shoot height, count, and classified seedlings into three grades. However, productivity was only 1000 seedlings per hour, a rate approximately three times slower than manual grading.

A digital electronic system for measuring and recording seedling diameter, height, root area index (silhouette area), and sample number was described by Buckley et al. (1978). Potentiometric transducers and a linear 1024 element photodetector were employed. Although measurements were accurate, the apparatus was much too slow to grade large quantities of seedlings at production line rates.

Digital image processing has been successfully implemented in many industrial and agricultural inspection processes. It has demonstrated high accuracy and throughput and has permitted 100% inspection in applications which were previously not feasible (Kranzler 1985). Machine vision inspection would appear to be an ideal tool for addressing the tree seedling grading problem.

OBJECTIVES

This study was initiated to investigate the ability of machine vision to grade bare-root pine seedlings under nursery production conditions. Specific objectives included:

1. Develop and implement a machine vision algorithm for obtaining grade classification measurements at production line rates,
2. Evaluate performance in terms of measurement speed, precision, and accuracy of classification.

METHODS AND MATERIALS

Assumptions

Several assumptions were adopted concerning the environment in which the grading would be performed. First, seedlings would be singulated, permitting only one seedling to appear within the camera field-of-view at a given time. Second, shoot orientation and lateral position would be loosely constrained. Finally, it was assumed that a black conveyor belt would be used to transport seedlings beneath the cameras.

Equipment

Equipment included a conveyor belt, machine vision computer, cameras, lenses, and lights. To simulate production grading operations, a variable-speed belt conveyor was constructed to transport seedlings for inspection. The black belt shiny surface was dulled by sanding to minimize specular reflection.

An International Robomation/Intelligence (IRI) D256 machine vision development system was used. Images were digitized into an array of 256 X 240 picture elements (pixels) with 256 grey levels. A high-speed hardware coprocessor performed computationally intensive operations such as image filtering and edge

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[1] Paper presented at the Intermountain Forest Nursery Association Meeting. [Oklahoma City, OK, August 10-14, 1987]

[2] Respectively, Professor of Agricultural Engineering, Oklahoma State University, Stillwater, OK, and Applications Engineer, International Robomation/Intelligence, Carlsbad, CA.

detection, runlength-encoding, and moments calculations. Software was developed in the C programming language.

Two Hitachi KP-120U solid-state black-and-white television cameras were employed for image acquisition. Camera 1 was used to obtain a close-up image of the seedling root collar zone. A field-of-view (FOV) approximately 12.8 cm (5 in) square provided a 0.5 mm (0.20 in) pixel resolution (fig.1). Camera 2, with a FOV approximately 51 cm (20 in) square and resolution of 2.2 mm, acquired an image of the entire seedling.

Illumination was provided by fluorescent room lighting and strobed xenon flash. Relatively low-level room lighting was adequate for detection of the moving seedlings in the FOV of camera 2. When a seedling was detected, synchronized strobe lamps were triggered to obtain a "frozen" image with each camera.

Grading Scheme

Morphological characteristics are used in the grading of most nursery stock. These characteristics include stem diameter at the root collar, shoot height and weight, root weight or volume, root fibrosity, foliage color, presence of terminal buds, root/shoot volume ratio, and ratio of top height to stem diameter (sturdiness ratio) (Forward 1982, May et al. 1982). Stem diameter, shoot height, and root volume are generally given priority and were adopted as the grading criteria for this study. Of these three, stem diameter is typically considered most important.

To meet image processing time constraints, we decided to emphasize stem diameter measurement accuracy and obtain close approximations of shoot height and of root volume as indicated by projected root area (root area index). A classification scheme based on minimum acceptable values of these three parameters (May et al. 1982) is given in table 1. Seedlings were graded into two classes; acceptable and cull.

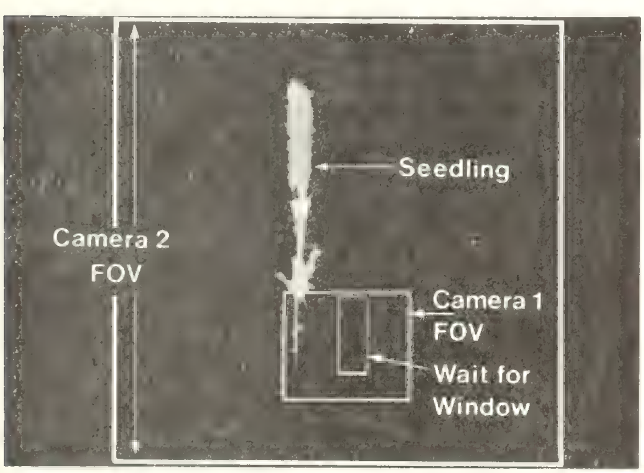

Figure 1. Field-of-view for cameras 1 and 2. Note Waitfor window.

ALGORITHM

The grading algorithm is composed of several separate tasks. These operations are: calibration, seedling detection, measurement of orientation, location of the root collar, diameter measurement, root area measurement, shoot height measurement, grade classification, and recording of seedling statistics. A detailed description of the algorithm is presented by Rigney (1986).

Accuracy of diameter measurement and the probability of the root collar appearing within the camera view influenced the choice of FOV for camera 1. Because the position of the root collar cannot be closely constrained, a relatively wide FOV is necessary. We decided to make the FOV as large as possible, while maintaining a measurement precision of at least 0.5 mm (0.20 in).

Seedling Detection

A program loop is entered in which successive images are acquired with camera 2 (wide FOV). Each image is multiplied by a template which defines a window in which seedling detection will trigger subsequent operations (Waitfor window, fig. 1). After grey-level thresholding, the area occupied inside the window is calculated. When the area exceeds a programmed number of pixels, the presence of a seedling is assumed, and an image is automatically acquired from each camera with strobe illumination.

Seedling Orientation

The image from camera 2 is next processed to determine shoot orientation on the conveyor belt. Coprocessor moments calculations provide the angle between the seedling major axis and a line perpendicular to the direction of travel. This angle is used as a correction factor in subsequent calculations of stem diameter and shoot height. Because measurement error becomes excessive at large angles, seedlings are not graded if the orientation angle is greater than thirty degrees.

Location of the Root Collar

Accurate location of the root collar is crucial for subsequent measurement of stem diameter, shoot height, and root area index. The image from camera 1 is thresholded, yielding a binary image showing the stem, roots, branches, and needles (fig. 2). This image is then runlength-encoded and processed line-by-line. The runlength code is an array of column numbers of the transitions from black-to-white and white-to-black on each line of a binary image.

If the number of transitions on a line is less than or equal to a selected variable (initially two), that line is a candidate for the root collar location. Additionally, from a priori knowledge about stem diameters, the maximum distance between paired transitions must be between 5 and 18 pixels (2.5 to 9 mm) for a line to be a root collar candidate. The root collar is located at the average of

Table 1.--Grading scheme for loblolly pine seedlings

Stem Diameter (mm)	Root Area Index (pixels)		Shoot Height (cm)	Grade
3.0 - 8.0	> 200		> 16	Acceptable
< 3.0 or > 8.0	any		any	Cull
3.0 - 8.0	< 200	or	< 16	Cull

the largest set of adjacent candidate lines, if that set contains at least six members. If the collar is not found using the initial value for number of transitions, the procedure is repeated for values of four and then six. When the root collar (line number) is found (fig. 3), it is stored along with the collar midpoint (column number) and number of adjacent candidate lines about the collar line.

If the root collar is still not located, the procedure is repeated after thresholding at a higher grey level. At this increased threshold, only the stem, major branches, and roots are visible (fig. 3). The use of two grey-level thresholds for collar location improves overall algorithm performance. A low threshold limits the number of candidate root collar lines for typical seedlings, reducing image processing time. A high threshold may be required to minimize the effect of needles, branches, and roots which are sometimes present in the root collar zone (figs. 2 & 3).

Measurement of Stem Diameter

Diameter measurement is performed inside a hardware window implemented about the root collar in the image from camera 1. Window size is defined by the set of candidate collar lines found in the collar location subroutine. The windowed zone is processed with an edge detector favoring vertical edges and thresholded, resulting in a binary image of the strongest stem edges (fig. 4).

The image is then runlength-encoded. For lines which contain four or more transitions (two transitions occur at each stem edge), the two consecutive odd transitions which bracket the collar midpoint are found. If these transitions are within ten pixels (5 mm, horizontally) of the collar midpoint, the distance between the transitions is assumed to be the stem diameter on that line. When the processing of candidate lines is complete, and at least one line has provided a distance measure, the stem diameter is calculated as the average of the diameters on candidate lines.

Measurement of Root Area Index

The image from camera 2 is initially windowed from the root collar to the bottom of the image and processed with a specialized edge detector. The image is then thresholded, yielding a binary image with a maximum number of root pixels and minimum background noise (fig. 5). The number of pixels inside the hardware window is defined as the root area index.

Figure 2. Camera 1 close-up image details root collar region.

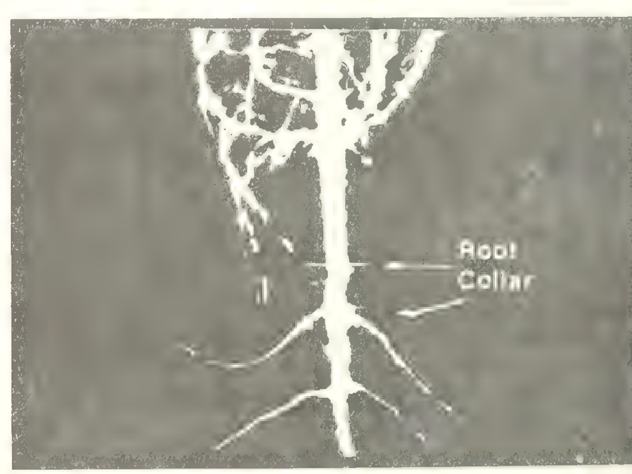

Figure 3. Algorithm locates root collar.

Measurement of Shoot Height

The image from camera 2 is thresholded and runlength-encoded. Starting at the top of the image, each line is checked to determine if the maximum distance between paired transitions exceeds five pixels. The seedling top is assumed to be located when four consecutive lines meet this criterion. Shoot height is defined as the distance between the seedling top and root collar.

Main Program

Inside the main program loop, values returned by subroutines are tested to control program flow. If all grading subroutines are successful in their respective tasks, a series of if-else statements is used to assign a grade to the seedling. Whenever a subroutine fails its task, the seedling is recorded as not gradable. Finally, measured seedling parameters, grade, and count, are written to a statistics file.

Calibration

Proper calibration of threshold values and scale factors is essential for optimum algorithm performance. The calibration subroutine initializes sixteen parameters with default values. The user is then provided an opportunity to alter the default values interactively. A wooden dowel of known diameter and length is used to calibrate scale factors. Grey level thresholds are set using a representative seedling.

EVALUATION

A reference set of 100 loblolly pine (Pinus tacda L.) seedlings was manually measured and graded. Stem diameters ranged from 2.3 to 6.0 mm. Performance of the machine vision system was then evaluated by grading each of the seedlings twenty times. Shoot orientation was limited to plus-or-minus thirty degrees from vertical,

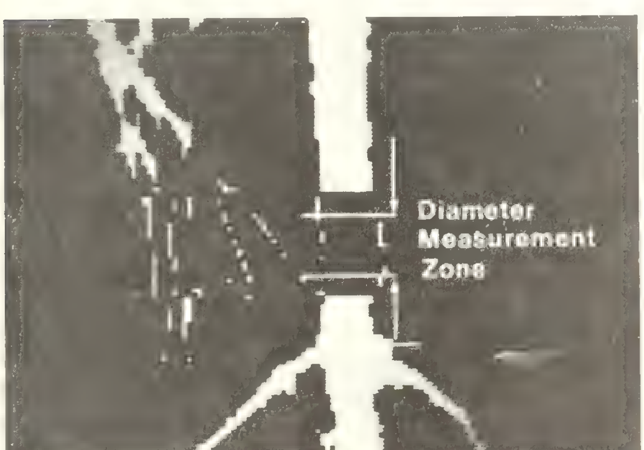

Figure 4. Image is processed to define stem edges in root collar zone.

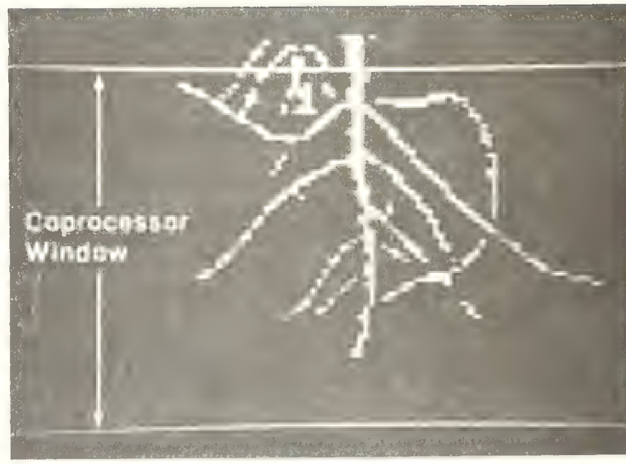

Figure 5. Image is processed to highlight seedling roots.

and root collar location was constrained to the FOV of camera 1.

Time required for the algorithm to grade a seedling averaged approximately 0.25 seconds. Strobe illumination provided reliable image capture at conveyor speeds of up to 1.0 m/s (3.28 ft/s), corresponding to a grading rate exceeding three seedlings per second. To facilitate manual placement of the seedlings on the grading belt, tests were conducted at a velocity of 0.46 m/s (1.5 ft/s).

The classification error rate averaged 5.7 percent for the set of 100 seedlings (table 2). This is very acceptable performance, bettering manual grading operations which have an average misclassification rate of seven to ten percent (Boeckman, 1986). As expected, a large part of the classification error was attributable to seedlings which straddled the borderline between acceptable and cull with respect to diameter and root area. Such seedlings comprised 17 percent of the grading test set and had an average misclassification rate of 23.2 percent. The remaining 83 seedlings had an average misclassification rate of 2.2 percent (table 2). Since there is no significant penalty for misclassification of borderline seedlings, 2.2 percent misclassification may be a better indicator of algorithm performance.

Measurement precision was excellent, considering the spatial resolutions of cameras 1 and 2, which were 0.5 mm/pixel and 2.2 mm/pixel respectively. The coefficient of variation of 20 measurement repetitions averaged 7.6, 12.2, and 4.1 percent for stem diameter, root area, and shoot height, respectively.

The few seedlings which showed the largest deviations in measured parameters were characterized either by needles extending down past the root collar, or by roots bent upward past the root collar, or both. The subroutine which located the root collar performed inconsistently on such seedlings. A few such seedlings could not be graded.

Table 2.--Percent misclassification of 100 seedlings, 20 reps

Manual Grade	Acceptable		Cull		Total		
	#	mis.	#	mis.	#	mis.	n.g.
Borderline	6	31.7%	11	18.6%	17	23.2%	2.6%
Easily Classified	63	2.2%	20	2.0%	83	2.2%	2.3%
All	69	4.7%	31	7.9%	100	5.7%	2.3

n.g. = not gradable   mis. = misclassified

We anticipate that algorithm performance could be enhanced with minor modifications. First, the shoot area could easily be measured, allowing calculation of a root/shoot ratio. Calculation of the sturdiness ratio (diameter/height) would also be straightforward. Collection of a data base with the machine vision system would allow implementation of a statistical classification scheme, leading to improved grading performance.

The measurement precision demonstrated by the algorithm suggests use for classification of seedlings into several acceptable grades. Additional grade definitions could be optimized for specific planting sites. Finally, we expect that the comprehensive statistics collected in a commercial implementation would make machine vision grading a valuable nursery management and research tool.

SUMMARY AND CONCLUSIONS

This study has demonstrated that machine vision can provide accurate production rate grading of harvested pine seedlings. Singulated seedlings were transported on a conveyor belt, with shoot orientation and root collar position loosely constrained. Seedlings were classified as acceptable or cull on the basis of stem diameter, shoot height, and projected root area.

Tests with loblolly pine seedlings revealed excellent system performance. Seedlings were graded in approximately 0.25 seconds, with an average classification error rate of 5.7 percent. These results exceed manual grading performance, which typically requires one second per seedling with an error rate of seven to ten percent. Misclassification was largely due to seedlings with borderline diameter and/or root area, and the occurrence of branches or roots in the root collar zone. Measurement precision was adequate for seedling classification into several grades, suitable for specific planting sites.

DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination is intended or endorsement implied.

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Mycorrhizae Nursery Management for Improved Seedling Quality and Field Performance[1]

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Abstract.--Nursery and field outplanting studies have repeatedly demonstrated that selected ecto- and endomycorrhizae on nursery seedlings reduce culls and improve field survival and growth. Mycorrhizae are significantly affected by nursery soil factors such as pH, drainage and moisture, fertility, and organic matter, and by cultural practices such as soil fumigation, cover crops, and pesticide applications. Seedling lifting, storage, and planting practices should be designed to retain the maximum number of feeder roots and associated mycorrhizae as possible. Inoculum of several species of ectomycorrhizae is commercially available, along with the necessary technology and machinery to be incorporated into standard bare-root and container nursery operations. Nurserymen and foresters are challenged to utilize mycorrhizae technology as an integral component of seedling production and forest regeneration.

INTRODUCTION

Seedling quality and field performance are largely governed by processes occurring under the soil surface in the root zone of seedlings. Absorption of water and nutrients is a function of the amount and quality of growing root tips or feeder roots. The feeder roots of most tree species are infected by specialized fungi that form beneficial associations called mycorrhizae (fungus-roots). These symbiotic structures greatly increase root absorption efficiency and are vital to the survival and growth of both the host tree and the fungus. Compared to nonmycorrhizal roots, those infected by mycorrhizal fungi have increased absorptive capacity, nutrient fixation, resistance to soil pathogens, and longevity. As the main interface between seedling and soil, mycorrhizae are a key measure of root system quality and are a vital component of integrated nursery management.

Figure 1.--Hardwood seedling feeder root infected with the endomycorrhizal fungus, Glomus sp. (left) and a mass of Pisolithus tinctorius (Pt) ectomycorrhizae on a southern pine seedling root (right).

Mycorrhizae are of two biological types: endomycorrhizae, which actually penetrate host cells; and ectomycorrhizae, which grow between the root cells and cover the root surface with a mantle of fungus hyphae (Fig. 1). Most hardwood

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tree species, including maple, sweetgum, sycamore, ash, walnut, and poplar, along with some conifers, including cypress, redwood, and arborvitae, form endomycorrhizae and depend on them for normal growth. This mycorrhizal type occurs on all agronomic crops, including nursery cover crops such as sorghum, corn, and the grasses. Ectomycorrhizal fungi are associated with tree species which include pine, spruce, fir, alder, beech, oak, and hickory. Both ecto- and endomycorrhizal fungi have very broad host ranges.

Endomycorrhizal fungi penetrate cortical cells of infected roots and form nutrient-exchanging structures (arbuscles) inside them. A loose network of fungal hyphae grows from the feeder root surface, extending the effective area of the root system. Endomycorrhizal roots absorb and utilize nutrients, particularly phosphorous, better than nonmycorrhizal roots. Thick-walled spores (vesicles) may develop in feeder root tissue, on the root surface, or in the root zone. These microscopic "vesicular-arbuscular" (VA) mycorrhizal fungi do not modify root morphology or produce conspicuous above-ground fruiting bodies, as do the ectomycorrhizal fungi.

Ectomycorrhizal feeder roots are visibly different from nonsymbiotic roots. They usually appear swollen, forked, more prolific, and differently colored. Fungal hyphae cover the feeder root in a dense mantle. Strands of fungal hyphae radiate into the soil and to the bases of fruiting bodies produced by these fungi. Ectomycorrhizal fungi depend on their hosts for simple carbohydrates, amino acids, and vitamins to complete their life cycles and produce their spore-disseminating fruiting bodies. They benefit their hosts by increasing water absorption and accumulation of nitrogen, phosphorous, potassium, calcium, and other nutrients (Marx 1977).

Extensive mycorrhizae research conducted by the USDA Forest Service and a number of cooperating forestry agencies has identified the primary functions of mycorrhizae in tree seedling physiology and the nursery management factors that limit mycorrhizal establishment. Technology has been developed recently for the artificial inoculation of bare-root and container nurseries with selected ectomycorrhizal fungi. Several types of commercial inoculum are currently available for selected ectomycorrhizal fungi and can be operationally utilized in forest tree nurseries. Techniques have been developed to identify and quantify ectomycorrhizae occurring on seedling root systems utilizing ectomycorrhizae as a measure of seedling quality. In numerous container and bare-root nursery studies, along with forest and reclaimed mineland outplanting studies, selected ectomycorrhizae have significantly increased seedling quality and field performance. Provided with this unique technology, nurserymen, foresters, and mineland reclamation specialists are challenged to understand and utilize mycorrhizae as an integral component of nursery seedling production and forest regeneration.

BENEFITS

Ectomycorrhizae

Most conifer tree species, including all pines, cannot grow without ectomycorrhizae. This obligate dependency of trees on their fungal symbionts has been thoroughly substantiated through extensive laboratory and field research, and through unsuccessful attempts to introduce tree species into areas where their symbiotic fungi were not present. After the ectomycorrhizal fungi were introduced, trees were successfully established (Marx 1980). In forest tree nurseries in the United States, there is seldom a total absence of ectomycorrhizal fungi. Seedlings form ectomycorrhizal associations with naturally occurring fungi that originate from windblown spores produced by fruiting bodies in adjacent windbreaks, seedling beds, or forest stands. In nurseries where cultural practices or new field conditions have reduced ectomycorrhizal fungus populations, seedlings grow poorly and do not respond to increased fertilization. Pockets of seedlings that do have ectomycorrhizae or even had ectomycorrhizae established earlier in the season, have increased stem caliper and height, improved foliage color, and a more balanced shoot:root ratio than adjacent stunted seedlings which are deficient in ectomycorrhizae.

The ectomycorrhizal fungi that occur most commonly in bare-root nurseries, such as *Thelephora terrestris* (Tt), are ecologically adapted to the favorable growing conditions in nursery soils. However, these fungi are poorly adapted to the adverse conditions of many reforestation and reclamation sites. Research by the USDA Forest Service has focused on one particular ectomycorrhizal fungus, *Pisolithus tinctorius* (Pt), which is especially tolerant of extreme soil conditions, including low pH, high temperature, drought, and toxicity. The conditions, which occur on many forest sites, inhibit other naturally occurring ectomycorrhizal fungi and their host trees (Marx, Cordell, and others 1984). Pt was selected because of its adaptability, ease of manipulation, wide geographic and host range, and demonstrated benefits to trees, both in the nursery and on reforestation and reclamation sites.

Many conifer and some hardwood species on a variety of nursery sites have been artificially inoculated with Pt by treating seedling containers and prefumigated nursery seedbeds (Fig. 2). Effective Pt vegetative inoculum has consistently improved the quality of nursery seedlings. National container and bare-root nursery evaluations have demonstrated the effectiveness of several formulations of Pt inoculum on selected conifer seedling species (Marx, Ruehle, and others 1981; Marx, Cordell, and others 1984). During the past 10 years, over 125 bare-root nursery tests have been conducted in 38 states. A companion evaluation of container seedlings also demonstrated the effectiveness of commercial Pt vegetative inoculum in 18 nurseries in 9 states

and Canada. Inoculated seedlings have significantly outperformed uninoculated checks (Fig. 3) that contained only naturally occurring ectomycorrhizae (predominantly Tt). Results obtained from 34 nursery tests conducted during 3 years showed that Pt inoculation of southern pine seedlings increased fresh weight by 17 percent, increased ectomycorrhizal development by 21 percent, and decreased the number of cull seedlings at lifting time by 27 percent (Fig. 4). The nursery failures that have occurred have been correlated with such factors as ineffective Pt inoculum, excessively high soil pH (above 6.5), improper nursery cultural practices, pesticide toxicity, or severe climate (Cordell 1985).

Inoculated seedlings have been planted on routine forestation sites, strip-mined areas, kaolin wastes, and Christmas tree farms scattered over the United States. Currently, over 100 Pt ectomycorrhizal outplantings involving 12 species

Figure 2.--Abundant Pt fruiting body production between 2-0 eastern white pine seedbeds prefumigated and inoculated with commercial Pt vegetative inoculum.

Figure 3.--1-0 loblolly pine seedlings with Pt ectomycorrhizae (left) and with only naturally occurring ectomycorrhizae (right).

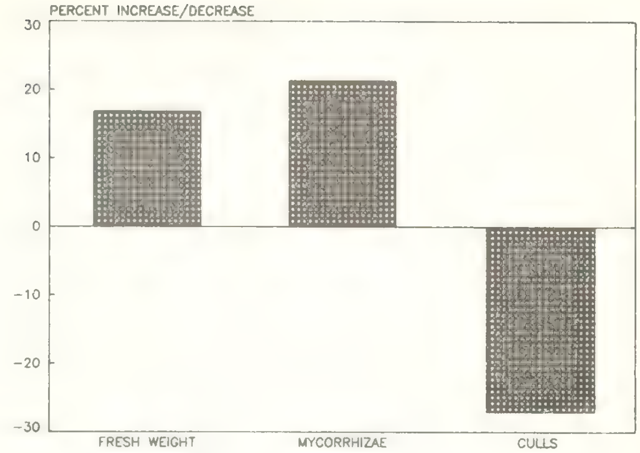

Figure 4.--Increases in seedling fresh weights and ectomycorrhizal development and decreases in the number of culls are obtained by inoculating seedlings with Pt.

of conifers are being monitored in 20 states. Over 75 of these outplantings contain southern pine species (primarily loblolly [Pinus taeda L.] and slash pine [P. elliottii Engelm. var. elliottii]) in the Southern United States. Most of these outplantings have been established since 1979; consequently, benefits to mature forest stands cannot be estimated. At widespread locations, however, tree survival and early growth of several conifer species have been significantly improved by Pt inoculations in the nursery. A significant increase (25+%) in tree volume is still being observed on Pt-inoculated eastern white (P. strobus L.), loblolly, and Virginia (P. virginiana Mill.) pines over check trees after 10 years in western North Carolina. Loblolly pine volume was 31 percent higher, and white pine volume was 151 percent higher than in uninoculated checks. Outplantings established by the Ohio Division of Mineland Reclamation on mineland reclamation sites in southern Ohio during 1982 and 1983 showed an average survival increase of 23 percent and 24 percent, respectively, for Virginia and eastern white pine seedlings over routine nursery seedlings after 2 years in the field. Treating longleaf pine (Pinus palustris Mill.) seedlings with Pt inoculum in the nursery increased their survival over uninoculated checks by 17 percent after 3 years in the field in four Southern States. Inoculation of longleaf pine with Pt, in combination with selected cultural practices in the nursery and a benomyl root treatment prior to field planting, has significantly increased the field survival and early growth of bare-root seedlings (Kais, Snow, and Marx 1981; Hatchell 1985).

After 8 years on a good-quality, routine forestation site in southern Georgia, a 50 percent increase was observed in volume/acre growth of Pt-inoculated loblolly pine over controls. The improvement was correlated with continued Pt-inoculated tree growth during seasonal periods

of severe water deficit.[5] Similar relationships have been found in other field studies. Root systems with abundant Pt ectomycorrhizae are apparently more capable of extracting water and essential nutrients from soil during periods of extreme water stress than are root systems with fewer ectomycorrhizae or with other species of ectomycorrhizal fungi. These reported benefits do not even show the full potential of Pt, because as the fungus thrived on inoculated treatment plots and spread to uninoculated plots, treatment integrity was lost after 3 years.

Endomycorrhizae

Any nurseryman who has encountered stunted, chlorotic hardwood seedlings in a prefumigated bed, despite proper fertilization, irrigation, and disease control, is fully aware of the benefits provided by endomycorrhizal fungi. Nursery studies have repeatedly shown increases in the quality of seedlings with endomycorrhizae, compared to those without endomycorrhizae (Fig. 5). Root and stem weight of black cherry, boxelder, green ash, red maple, sweetgum, sycamore, and black walnut seedlings were significantly increased following treatment with VA mycorrhizal fungi (Kormanik, Schultz, and Bryan 1982). Black walnut seedlings grown in nursery soils infested with VA fungi retained their leaves longer, extending the effective growing season by 6 to 8 weeks and resulting in greater root and shoot biomass production (Kormanik 1985). Benefits from endomycorrhizae were greatest at phosphorous levels below 75 ppm (150 lb/acre). At higher soil phosphorous concentrations, nonmycorrhizal seedlings grew as well as endomycorrhizal seedlings (Kormanik et al. 1982; Kormanik 1985). In field studies where available phosphorous was low (10-15 ppm), hardwood seedlings that had abundant lateral roots and endomycorrhizae did not die back as much after outplanting as those with few lateral roots and poor endomycorrhizal development. In most forest soils, long-term benefits from endomycorrhizal treatments in the nursery are difficult to determine because nonmycorrhizal root systems are quickly colonized by naturally occurring VA fungi (Kormanik 1985).

Figure 5.--Inoculation with a VA endomycorrhizal fungus increased seedling biomass of eight hardwood species (left) compared to noninoculated seedlings (right).

Figure 6.--Observed correlation between increased number of sweetgum seedling primary lateral roots (= or > 1 mm diameter) and improved seedling quality.

In the extended process of evaluating root system development in relation to VA fungi, a high correlation was found between the number of primary lateral roots (1 mm or more in diameter) and seedling performance after outplanting. In a 1-year-old sweetgum plantation, height, root-collar diameter, and survival increased and top dieback decreased (Fig. 6) as the number of lateral roots increased (Kormanik 1986). The previously observed correlation between the number of lateral roots and seedling quality remained consistent as additional tree species were examined. Findings may be applicable to conifers as well as hardwoods and ecto- as well as endomycorrhizal host trees. While the effects of lateral root morphology appear to be independent of mycorrhizal condition, they demonstrate the importance of assessing root systems as a component of seedling quality.

Identification and Quantification

A nurseryman who hopes to maximize seedling quality should learn to recognize and perhaps quantify the dominant mycorrhizal types occurring on seedlings. Ectomycorrhizal fungi are most easily identified by their fruiting bodies--the numerous puffballs or mushrooms that develop some time after seedlings have been colonized. The fungi can also be recognized on the basis of distinct morphology of ectomycorrhizal feeder roots. Although over 2,000 ectomycorrhizal fungi are known, only a few (1 to 3) species usually are found in a nursery. On western fir, spruce, and pine seedlings, gilled mushrooms of Laccaria

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[5] Marx, D.H., C.E. Cordell, and A. Clark. 1987. Eight-year performance of loblolly pine with Pisolithus ectomycorrhizae on a good quality forest site. Manuscript in press. USDA Forest Service, Southeastern Forest Experiment Station, Institute for Mycorrhizal Research and Development, Athens, Ga. [Submitted to Southern Journal of Applied Forestry.]

(Fig. 7a) and Hebeloma (Fig. 7b) species, pored mushrooms of Suillus species (Fig. 7c), and puffballs of Rhizopogon species (Fig. 7d) are common. On or near pine seedlings in the South, puffballs of Pisolithus tinctorius (Fig. 7e) and the papery thin, funnel-shaped mushrooms of Thelephora terrestris (Fig. 7f) frequently occur. Puffballs of Rhizopogon species, which have white, homogeneous centers, can easily be distinguished from those of Pisolithus tinctorius by their lack of peridioles or small sacs of spores within the context. Recognizing and separating ectomycorrhizal species on the basis of root morphology requires a trained eye, but the different colors and shapes of ectomycorrhizae can be distinguished with practice. Whereas nonmycorrhizal feeder roots are generally thin, with texture and color similar to the larger roots, ectomycorrhizae usually are swollen, forked or many-branched, and differently textured and colored from the rest of the root system.

During quantitative and qualitative seedling evaluations, a relative measure of the amount of mycorrhizal occurrence is more useful than identification of the ectomycorrhizal fungi on a sample of seedlings. Sampling techniques have been developed to estimate the proportion of a seedling's feeder roots that are ectomycorrhizal. In measured lengths of lateral roots, numbers of feeder roots with and without ectomycorrhizae are counted (Anderson and Cordell 1979). Such laborious examinations may be required for research studies, but they are impractical for estimates

Figure 7.--Characteristic ectomycorrhizal fungus fruiting bodies of (a) Laccaria sp., (b) Hebeloma sp., (c) Suillus sp., (d) Rhizopogon sp., (e) Pisolithus tinctorius, and (f) Thelephora terrestris.

of large quantities of operational seedlings. A reliable estimate can be determined by visual examination of seedling root systems that have been rinsed clean in water. An estimated percentage of ectomycorrhizal feeder roots is assayed to each seedling and averaged for the whole seedling sample. With experience, a seedling can be evaluated in a matter of seconds. These estimates provide values that can be compared among samples, inventory dates, or even different crop years. As nursery management practices are refined, it becomes possible to monitor the mycorrhizal component of seedling quality.

Unlike ectomycorrhizae, the VA endomycorrhizal fungi produce no morphological changes or structures visible to the unaided eye. Endomycorrhizae can only be identified by their microscopic hypha and vesicle morphology, and by the host association in which they occurred. In bare-root nurseries, seedling stunting, chlorosis, and top dieback are often indicators of poor endomycorrhizal development. Endomycorrhizal deficiencies may result from soil fumigation or from fungicide applications that eliminate or drastically reduce soil populations of the fungi. Endomycorrhizal deficiencies also occur in new seedling production areas with insufficient populations of appropriate endomycorrhizae. Although endomycorrhizae can be identified and quantified, monitoring for possible deficiency symptoms appearing among endomycorrhizal seedings is more practical.

MYCORRHIZAE NURSERY MANAGEMENT

Endomycorrhizae or ectomycorrhizae in nurseries can be increased by modifying nursery management practices, as well as by artificial mycorrhizal inoculation. Guidelines for mycorrhizal nursery management pertain more to maintaining healthy seedling root systems than to the requirements of a particular species of mycorrhizal fungus. Enhancement of mycorrhizal fungi is inseparable from increased seedling quality. Management for increased mycorrhizal development is not limited solely to establishing the symbiotic structures on roots. One must consider development and retention of seedling feeder roots and mycorrhizae from seed sowing to seedling lifting in the nursery and to planting the trees in the field. Nurserymen, field foresters, and tree planters must be made aware of the two symbiotic living organisms they are handling--the tree seedling and its complement of mycorrhizal fungi.

Soil and Cultural Factors

Nurserymen strive to maintain optimal soil conditions for seedling growth. Having evolved with their host trees, mycorrhizae generally require the same moisture, fertility, and pH as the tree seedlings, but tolerance for extreme or adverse conditions does vary. Mycorrhizae are adapted to the full range of forest soils, from

heavy clays to coarse sands, but their responses to nursery practices vary with the soil type. For example, ectomycorrhizae on southern pine seedlings in deep sands may have much reduced tolerance of the systemic fungicide triadimefon (Bayleton) as compared to ectomycorrhizae occurring in clayey nursery soils. Soil fumigation with methyl bromide formulations is generally more effective in lighter, sandy soils than in heavy clays, which bind the chemical and prevent complete penetration. Similar interactions between soil texture and composition and mycorrhizae may occur for other cultural practices, including irrigation, fertilization, and application of other pesticides.

Soil pH

The pH of nursery soils has a profound effect on mycorrhizal establishment and growth. As a measure of the balance of acid and basic chemical activity in a soil, pH indicates limitations to the availability of nutrients, the pattern of nutrient absorption and exchange in the root zone, and even the composition of micro-organisms (mycorrhizal fungi, saprophytes, and soil pathogens) in the root zone. Although mycorrhizal synthesis occurs on trees in soils with wide pH ranges throughout the world, pH of nursery soils should approximate the optimum for the tree species and the forest soil type. For endomycorrhizae on hardwoods, Kormanik (1980) recommended maintaining soil pH between 5 and 6. He cited a study in which satisfactory endomycorrhizal synthesis and sweetgum seedling growth occurred at pH 4.5 and 5.5, but not at pH 6.5 or 7.5. Ectomycorrhizae also are usually favored by slightly acidic soils, and some, such as Pt, are severely inhibited by soil pH over 6.5. Most ectomycorrhizal fungi have a pH optimum between pH 4 and 6 when grown in pure culture, but by manipulating the amount and chemical formulation of nutrients, this range can be extended or shifted to more acidic or alkaline pH optimums.

The indirect effect of soil pH on nutrient availability in soils may be more important in mycorrhizae formation than the direct effects of pH on the fungus (Slankis 1974). All the macronutrients are more available above pH 6. Pt thrives in nursery soils under standard fertilization regimes, at pH 4.5 to 5.5, and on acid mine spoils with soil pH as low as 3. Vegetative inoculum formulations of Pt produced at pH greater than 6.0 were not as effective as inoculum produced at pH below 6.0 (Marx et al. 1984). An additional hazard of high soil pH in the production of both conifer and hardwood seedlings is the increased activity of soil pathogenic fungi, such as Fusarium and Pythium, which cause damping off and root rot.

Soil Drainage and Moisture

For satisfactory mycorrhizal development and seedling growth, nursery soils must have adequate soil drainage but sufficient soil moisture. In dry soils, free water is unavailable to roots, and nutrient absorption and exchange stop. However, irrigation generally maintains adequate soil moisture for seedling growth. In soils with excess water, oxygen deficiency inhibits the growth of both symbiotic fungi and tree roots. Respiration is greater in mycorrhizal roots than in noninfected roots. Prolonged flooding profoundly changes root physiology, decreasing phosphorous fixation, decreasing permeability to water and nutrients, arresting growth, and eventually killing roots (Slankis 1974). Seedlings grown in poorly drained soils are subject to damping off and root rot diseases caused by fungi with spores motile in water, such as Pythium and Phytophthora. Where drainage is poor, soil conditions must be improved by leveling, subsoiling, or adding amendments.

Soil Fertility

As with other soil factors influencing mycorrhizal development, fertility should be maintained at levels required for ample host seedling growth. Excessively high levels of certain nutrients, particularly nitrogen and phosphorous, may change chemical balances within seedling root systems, limiting mycorrhizal infection. As pH rises above 6, high phosphorous and nitrogen levels may be especially discouraging to mycorrhizal fungi. With soil pH at or below 6, however, seedlings grown under high fertility (especially nitrogen) have produced abundant Pt ectomycorrhizae. Hardwood seedlings grown under high phosphorous fertility (greater than 200 ppm) have reduced endomycorrhizal synthesis (10-35% down from 40-75%) without reducing seedling growth. Kormanik (1980) recommends maintenance of 75 to 100 ppm phosphorous for good hardwood seedling and VA mycorrhizal development. Kormanik also recommends up to 10 applications of nitrogen, totaling 500 lb/acre, scheduled to capture late season height growth of hardwood seedlings following root development. Increasing total nitrogen from 250 to 500 lb/acre was accompanied by a 50-percent increase in height growth and approximately a 40-percent increase in root collar diameter of endomycorrhizal sweetgum seedlings, justifying the added nitrogen cost.

Soil Fumigation

Effective soil fumigation is necessary to control against weeds, nematodes, insects, and injurious soil fungi. Unfortunately, fumigation also kills existing populations of mycorrhizal fungi. Ectomycorrhizal fungi are quickly replenished by high numbers of windblown spores from mushrooms and puffballs. Replenishment occurs so readily in most nurseries, that spring rather than fall fumigation is required before artificial ectomycorrhizae inoculations to minimize competition from these naturally occurring fungi.

Spread only by physical movement of soil and water, endomycorrhizal fungi are slow to return

to prefumigation levels. VA fungi populations are highly variable in fumigated areas and build up in the soil only after one or more crops are grown. By growing cover crops between soil fumigation and sowing of tree seedlings, endomycorrhizal populations are at effective levels for seedling production. If certain soil pathogens, such as Cylindrocladium sp., were not of greater danger than having insufficient endomycorrhizae, soil fumigation should be avoided all together.

Cover Crops

In addition to building up endomycorrhizal populations, cover crops between seedling crops rest the soil, increase organic matter content, and improve soil structure. Crops of corn, sudex, sorghum, millet, or grasses are effective in building up VA fungi in the plant roots and in soil. Winter as well as summer cover crops will increase endomycorrhizae. Although sorghum induced highest densities of VA fungal spores, sweetgum seedlings grown in compartments planted with corn, millet, sudex, and sorghum were of comparable quality and size (Kormanik, Bryan, and Schultz 1980). Crops with longer growing seasons have greater potential for root growth and spore production. Use of any cover crop after fumigation must be accompanied by careful monitoring of any chronic soil-borne disease problems that may occur in particular nursery soils.

Pesticides

Many pesticides of various types are used in nurseries, and the effects of individual chemicals on seedling growth or mycorrhizal synthesis are seldom known. The effects of herbicides and insecticides on mycorrhizae are particularly unexplored. However, many effects of commonly used fungicides have been documented. The fungicides captan and benomyl are recommended for use in conjunction with operational Pt inoculation of bare-root nurseries. Metalaxyl (Ridomil or Subdue), an effective fungicide against Phytophthora root rot, has no deleterious effect on ectomycorrhizae on Fraser fir when used at recommended dosages. Perhaps the most widely used fungicide in southern pine nurseries is the systemic fungicide, triadimefon (Bayleton), used to control fusiform rust. Triadimefon seed treatments which provide rust control through southern pine seedling emergence, have no negative impact on naturally occurring or artificially-introduced ectomycorrhizal fungi. However, foliar applications applied three to four times during the rust season (May-June) suppress ectomycorrhizal development until late in the growing season. Pt ectomycorrhizae are particularly susceptible to this fungicide. Normally, by lifting time, naturally occurring ectomycorrhizae, mostly Thelephora terrestris, have recolonized the root system. Negative impact on seedling quality is hotly debated, but the effects on mycorrhizae are well substantiated. Any and all pesticides, prior to operational use in nurseries, should be evaluated for their effects on mycorrhizal development as well as seedling growth.

Shading

Shade-tolerant conifer seedlings require some degree of physical shading. Too much shading reduces photosynthesis and soil temperatures to the degree that mycorrhizae cannot form. The optimum level of shade must be found that protects seedlings from scorching but does not inhibit mycorrhizae.

Root Pruning

At the proper depth and distance from seedlings, root pruning stimulates formation of compact root systems and increased mycorrhizal development. Injury of the root tips initiates greater carbon allocation to the root system, which causes the increased root growth. This practice increases the amount of mycorrhizal feeder roots proximal to the seedling stem, effectively increasing the amount of mycorrhizae that will be retained with the seedling during lifting and handling.

Seedling Lifting, Storage, and Planting

Special care must be taken during all stages of seedling handling to maintain sufficient root systems and mycorrhizae. Mycorrhizae are delicate structures. They can be ripped off and left behind in seedling beds during lifting, desiccated in storage, or cut off prior to field planting. For sustained seedling quality, lifting and handling techniques must be modified to minimize damage to feeder roots and mycorrhizae. Stripping of roots adds severe negative impacts on seedling field performance (Marx and Hatchell 1986). Full bed seedling harvesters are less destructive than single- or double-row lifters. Condition of the root systems should be checked during the entire lifting process; even slight reductions in tractor speed can greatly reduce damage to the roots as seedlings are lifted.

During transfer of seedlings from the field to the packing room and at all other times when seedlings are handled, special care is required to avoid drying of the roots by exposure to wind and sun. The procedure by which seedlings are packed influences their ability to endure storage and survive field planting. If extended storage is required, Kraft paper bags with a polyethylene seal will maintain seedling moisture better than seedling bales. Cold storage is vital to slow seedling respiration. Studies comparing packing material have determined that seedling survival is better when peat moss, clay, or inert superabsorbents are used rather than hydromulch (Cordell, Kais, Barnett, and Affeltranger 1984). The material should be distributed through the bag, not simply dumped at the bottom or top. Better results are obtained when all root systems are coated or at least in contact with the pack-

ing material. Numerous studies have documented the effects of long-term storage on seedling quality. For most tree species and their mycorrhizae, storage for 2 to 6 weeks is not harmful. Beyond the threshold for each species, however, significant negative effects can occur.

Seedling quality is vulnerable to any one or more limiting factor. Even if quality is maintained through seedling growth, lifting, and storage, it could still be severely reduced by improper transportation to the planting site or rough handling during planting. Tree planters should understand proper planting methods and the reasons for them. Where possible, seedlings should be transported under refrigeration. If that is not possible, they should be covered and stacked with spacers to avoid high temperature buildup inside the seedling containers. For machine or hand planting, root pruning at the planting site should be avoided because it eliminates carefully nurtured feeder roots and mycorrhizae. High temperature, high winds, and low humidity kill feeder roots and mycorrhizae very rapidly. The first priority in planting should always be to maintain seedling viability and vigor. The rate at which acres are planted is of no consequence if the seedlings do not survive.

Ectomycorrhizal Fungus Inoculations

Ectomycorrhizal Fungus Inoculum

Until recently, artificial inoculation of Pt or any other ectomycorrhizal fungus species was limited because procedures, commercial fungus inoculum, and necessary equipment were not readily available to nurserymen. The USDA Forest Service has been cooperating with several private companies to develop different types of commercial ectomycorrhizal inoculum, along with equipment and procedures needed for inoculating bare-root and container-grown seedlings. In addition to Pt ectomycorrhizal inoculum, strains of Hebeloma sp., Laccaria sp., and Scleroderma sp. are currently available. The types of Pt inoculum that are available are vegetative inoculum from Mycorr Tech, Worthington, Pennsylvania, spore pellets, spore-encapsulated seeds, and bulk spores from either International Forest Tree Seed Co., Odenville, Alabama, or SouthPine, Inc., Birmingham, Alabama. A nursery seedbed applicator (Fig. 8) has been developed to accurately place Pt vegetative inoculum in seedbeds prior to sowing in bare-root nurseries. Inoculum is applied in bands under seed rows at desired depths (Fig. 9). Use of the applicator has reduced the amount of vegetative inoculum needed by 75 percent and reduced time and labor requirements as compared to broadcast application.

Inoculum Costs

There is a wide range in the cost of commercial Pt inoculum (Table 1). Cost of the each inoculum type also varies with such factors as

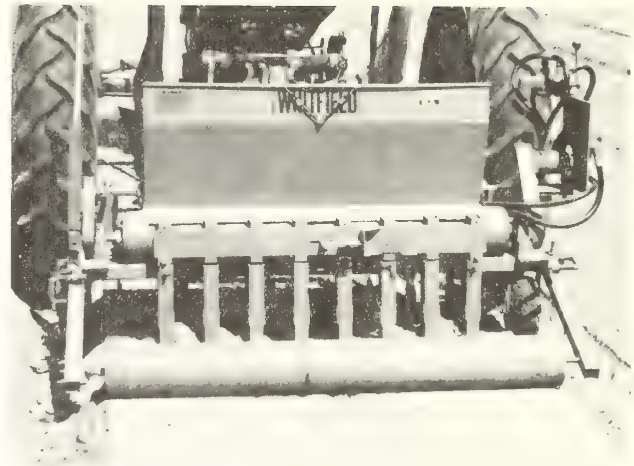

Figure 8.--A commercially available machine applies bands of commercial Pt vegetative inoculum to a bare-root nursery seedbed.

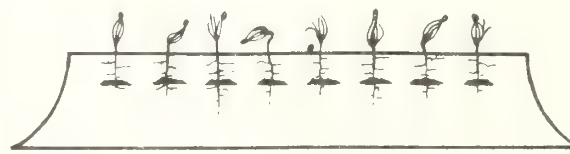

Figure 9.--Diagram of a bare-root nursery seedbed shows bands of Pt vegetative inoculum under seedling rows in root zones.

Table 1.--Commercial Pt inoculum costs.[1]

Pt inoculum type	Inoculum cost per 1,000 seedlings	planted hectare	planted acre
Vegetative mycelium	$10.00	$17.94	$7.26
Spore-encapsulated seeds	$ 2.22	$ 3.98	$1.61
Spore pellets	$ 2.75	$ 4.93	$2.00
Double-screened[2] bulk spores	$ 0.43	$ 0.77	$0.31

[1]Cost estimates are for loblolly and slash pine bare-root nurseries (269 seedlings/m^2 or 25 seedlings/ft^2) and forest plantings (1.8 x 3.0 m or 6 x 10 ft. spacing; 1,794 trees/ha. or 726 trees/ac.) in the Southern United States.

[2]Double screening is required for even flow through spray nozzles. Standard bulk spores are only screened once.

nursery seedling density, seed size for spore-encapsulated seeds, and field planting spacing. In 1987, the Pt vegetative inoculum costs for bare-root nurseries per unit of forest product were reduced 25 percent by increasing nursery seedbed inoculation efficiency, improving effectiveness of inoculum, and decreasing application rates. The vegetative mycelium is sold on a volume (liter) basis, while the spore inocula are all sold on a weight (pound) basis.

Inoculation Procedures

Operational procedures vary among the different commercial Pt inoculum types, but with any inoculum, the biological requirements of a second living organism are added to those of the seedling. Special precautions are necessary for shipping, storing, and handling the Pt inoculum, as well as for lifting, handling, and field planting of seedlings. For successful Pt inoculation in bare-root seedbeds, populations of pathogenic and saprophytic fungi and native ectomycorrhizal fungi that may already be established in the soil must be reduced by spring soil fumigation. Prior to spring sowing, vegetative inoculum can be broadcast on the soil surface and incorporated into the fumigated seedbeds or it can be machine-applied with greater effectiveness and efficiency. For container-grown seedlings, vegetative inoculum can be incorporated into the growing medium before filling the containers or placed at selected depths in the growing medium in the container. Bulk spores can be sprayed, drenched, or dusted onto growing medium for containerized seedlings and onto seedbeds in bare-root nurseries. Spore pellets can either be incorporated into the growing medium or seedbed soil, or they can be broadcast on the soil surface, lightly covered, and irrigated. Spore pellets have been applied at several nurseries with a standard fertilizer spreader (Fig. 10). Spore-encapsulated seeds can be sown by conventional methods. A major disadvantage of the Pt spore inoculum is the absence of a reliable means of determining or controlling spore viability. Consequently, Pt ectomycorrhizal development has been considerably less consistent and effective with spore inoculum than with vegetative inoculum.

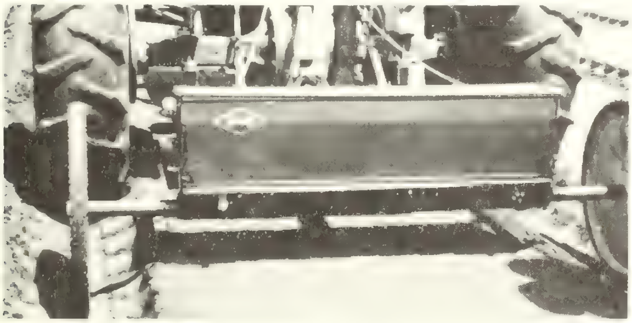

Figure 10.--Commercially available Pt spore pellets are applied to a nursery seedbed with a standard fertilizer applicator.

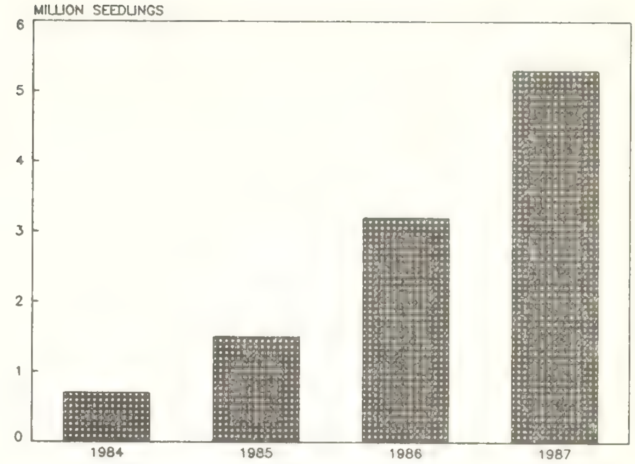

Figure 11.--Increased Pt-inoculated custom seedling production in bare-root and container seedling nurseries, 1984-87.

Operational Applications

The demand for Pt-tailored nursery seedlings has significantly increased during the past 4 years, despite the added costs and financial difficulties that most forestry agencies are currently experiencing. Since 1984, annual demand for tailored seedlings has increased 10-fold from 0.5 million to 5 million seedlings (Fig. 11). During the spring of 1986, Pt vegetative inoculum was operationally applied at 10 bare-root nurseries in the Southern and Central United States. Approximately 2 million seedlings of 9 conifer and 1 hardwood species were produced. In addition, over 1 million pine seedlings were inoculated with spore pellets. During the spring of 1987, Pt vegetative inoculum was applied at five bare-root nurseries in the Southern and Central United States. More than 3 million seedlings of five conifer and one hardwood species were inoculated. More than 2 million seedlings are being produced at a South Carolina State nursery for the USDA Forest Service, Savannah River Forest Station, and the United States Department of Energy. This represents the largest single application of an ectomycorrhizal fungus in a forest tree nursery to date. Over 2 million additional pine seedlings were inoculated with spore pellets at two bare-root nurseries in North Carolina and South Carolina and a container seedling nursery in Alabama.

Endomycorrhizal Fungus Inoculations

Although the technology required to produce VA mycorrhizal inoculum and to inoculate soils and plants is available and in use on certain agricultural and orchard crops that are highly dependent on endomycorrhizae, artificial inoculation of forest tree seedlings is not generally feasible. For most tree species, the phosphorous threshold is low enough that increased fertilization can remedy the effects of endomycorrhizal deficiencies. In addition, within several

months, indigenous VA fungi on most reforestation sites colonize root systems of seedlings that were deficient in endomycorrhizae at the nursery. However, artificial inoculation may be beneficial if continued endomycorrhizal deficiencies and subsequent reductions in seedling quality occur at a nursery despite modifications in fertilization, fumigation, and crop rotation.

Different methods of artificial inoculation with variable potential benefits may be utilized. Nurserymen can add endomycorrhizal forest soils to the nursery soil, add soil from an area previously used to produce endomycorrhizal seedlings, or build up VA fungi populations through cover cropping. Soil or roots from the cover crop area can be spread over a deficient area and tilled into the soil. A potential problem with any of these methods is that soil pathogens can be introduced or increased by the same processes that introduce or increase VA fungi. Commercially available pot cultures of endomycorrhizal hosts grown under aseptic conditions can provide potentially cleaner and more effective inoculum consisting of soil and roots. Various types of VA fungal inocula are currently produced by NPI (Native Plants, Inc.), Salt Lake City, Utah 84108. This endomycorrhizal "starter" inoculum can be used to introduce appropriate VA fungi into fumigated or naturally deficient soils. Cover cropping can then be used to build up the VA fungal populations to effective levels for the production of endomycorrhizal seedlings.

CONCLUSION

Symbiotic relationships between tree seedlings and mycorrhizal fungi are the rule in nature. Conifer and hardwood nursery seedlings require adequate quantities and quality of either ecto- or endomycorrhizae to meet seedling quality standards. Minimum quantities or amounts of mycorrhizae are required to provide adequate field survival and growth. For southern pines produced in bare-root nurseries, this minimum ectomycorrhizae quantity has been established at 35 percent of the total seedling feeder roots on 90 percent or more of the seedlings. It should be emphasized that this 35 percent must be present when the pine seedlings are planted in the field. The quality of ectomycorrhizae for a planting site depends on the host tree-fungus species combination; optimum combinations can be produced by inoculating seedlings for specific applications, such as mineland reclamation. Custom production of mycorrhizal seedlings has been incorporated into bare-root and container nursery operations. The quality of mycorrhizae and of seedlings can also be improved through careful management of existing ecto- or endomycorrhizae.

Regardless of the selected alternatives, nurserymen, field foresters, and tree planters must be aware that they are dealing with two symbiotic living organisms--the tree seedling and the mycorrhizal fungus. Both must be nurtured to provide seedlings of the highest quality for field forestation. The tree seedling-mycorrhizal fungus symbiotic relationship is an integral component of nursery seedling production. Any estimates of seedling quality that exclude quantitative and qualitative mycorrhizal assessments are incomplete and unrealistic.

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Integrated Pest Management in Forest Nurseries[1]

T. H. Filer, Jr. and C. E. Cordell[2]

Abstract.--INPM techniques and procedures provide the necessary information to assist nursery managers in planning the most effective practices to produce quality seedlings. An integrated program that considers the following factors will minimize losses from diseases, insects, and weeds: site selection, fumigation, crop rotation, cover crops, sowing date, fertilization, irrigation, seedbed density, and chemical and biological control methods.

INTRODUCTION

Conservation reserve and other tree planting programs have caused an accelerated rate of reforestation in the United States, which has caused an increase in seedling production. New state and industry nurseries are being established, as well as old ones being expanded. More than 80 industry, state, and federal nurseries in the South produce over 1 billion seedlings annually. This represents over 75% of the total annual bare-root production in the United States. Nurseries grow a wide variety of both conifers and hardwood species.

Increased production and tree species confront nursery managers with a wider array of potential pest problems. The high value of genetically improved seedlings has significantly increased the impact of pest problems.

Seedling quality represents the most important economic aspect of forestation. However, seedling cost will average less than 15% of total plantation establishment cost per acre. To meet future wood demands, high quality and quantity of tree seedlings must continue to be available to the forest manager.

Major pest problems in the nursery are an exception rather than the rule. When major problems do occur, nursery managers can utilize integrated pest management practices.

The integration of suitable techniques and procedures into one concerted, harmonious effort is needed for effective, efficient control of nursery pests.

Integrated Nursery Pest Management (INPM) is defined as the reduction of pest problems in the nursery by employing decisions, plans, and a combination of management procedures in a coordinated pest management program. This system, to be successful, requires a systematic, interdisciplinary approach from such related disciplines as soil science, silviculture, forest pathology, entomology, and weed science. Emphasis must be placed on pest prevention, containment, and exclusion.

Nursery pest management practices are closely related to and must be harmoniously used with prescribed cultural practices to be practical and effective. The selection of the most effective, practical, and environmentally safe combination of INPM practices for target pest problems is the key to successful pest management.

PREVENTION

An effective quarantine program will prevent the transfer and spread of pathogens, nematodes, insects, and weeds into nursery and field forestation areas. These pests may be present on seeds, seedlings, soil, water, equipment, or personnel. Preventive measures represent the most effective and efficient pest management practice.

PEST DETECTION, DIAGNOSIS, AND EVALUATION

Early pest detection, combined with rapid diagnosis of problems, is a prerequisite to successful nursery pest management. Rapid diagnosis will permit the selection and timely application of control procedures before the pest becomes unmanageable.

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NURSERY SITE SELECTION

Selection of the nursery site is the most important cultural practice for consideration in the nursery pest management plan. Select new locations or expand existing nurseries only after considering the following factors and their relationship to pest management: soil types, texture, pH, past land use, presence of harmful pests, adequate supply of clean water with proper pH. The soil type for most tree species should be of a coarse texture, primarily sand with some silt and a low clay content. The soil profile should not have any impermeable subsoil. This type of soil promotes good tillage, fumigation, and drainage. Preemergence damping-off, caused by soil-borne fungi, is less severe in coarser soil with good drainage. The pH of soil and irrigation water can influence the development of soil-borne diseases. Pre- and post-emergence damping-off diseases often occur in conifers when the soil pH exceeds 6.0.

CROP ROTATION

Crop rotation is used in INPM programs to reduce seedling losses from fungi, insects, nematodes, and weeds. The pests often become serious problems when continuous seedling production is practiced without rotation. Alternating susceptible and nonsusceptible crops in proper sequence will minimize seedling losses. The alternation of cover crops with seedling production is standard practice in many forest tree nurseries.

COVER CROPS

Cover crop species vary in their susceptibility to different root rot pests. Corn, peas, soybeans, and sorghum are susceptible cover crop hosts for charcoal root rot of conifers (Seymour and Cordell 1979). Alfalfa, soybeans, and other legumes are susceptible to the Cylindrocladium root rot fungus of hardwoods (Cordell and Skilling 1975).

To allow for adequate decomposition, cover crops should be plowed under a minimum of 2 months before fumigation. Non-decomposed organic matter will absorb large quantities of fumigants, thereby reducing pest control. Organic matter amendments may reduce root pathogens because increased organic matter promotes high populations of saprophytes and soil organisms that compete with root pathogens.

ORGANIC MATTER AMENDMENTS

Annual applications of organic matter to nursery beds help to improve tilth, nutrient, water retention, and soil aeration. However, precautions are required concerning the type and composition. The addition of fresh sawdust or pine bark may have adverse effects on tree seedling development by changing the carbon/nitrogen ratio of the seedbed. Micro-organisms tie up the available nitrogen and the seedlings suffer from nitrogen deficiency.

SOIL AND WATER PH

Soil pH, excessively high or low, influences the severity of diseases caused by soil-borne fungi. The addition of elemental sulfur is useful to lower soil pH and reduce disease losses such as damping-off on conifer and hardwood seedlings. The addition of lime will increase the soil pH to more desirable levels. The pH of irrigation water can be lowered by metering sulfuric or phosphoric acid into the irrigation system. Desirable soil and water pH levels range between 5.0 and 6.0.

SEEDBED SOWING DATES

Minimize seedling losses from soil-borne pathogens by selecting the proper planting date. Cold, moist soils are conducive to growth and development of Pythium and Phytophthora fungi that cause pre- and post-emergence damping-off of seedlings (Filer and Peterson 1975). A delay in spring seeding until soil temperatures are favorable for seed germination will often avoid losses from damping-off fungi.

In the southern states, an equally serious problem is high soil surface temperature in late spring, which causes sun scald of young seedlings. Fall sowing is an alternative choice to avoid sun scald problems of several hardwood species.

SEEDBED DENSITY

The correct seedbed density will reduce certain pest problems. Seedbeds planted too dense, increasing competition for the available soil nutrients and water, will result in reduction in seedling growth and vigor. Poor seedling vigor increases susceptibility to diseases and insects. High seedbed density also reduces air circulation, which results in more foliage diseases. The increased demand for seedlings to meet accelerated reforestation programs suggests a possible trend to denser nursery seedbeds.

MULCH FUMIGATION

Mulches, such as pine needles and grain straw, should be fumigated to eliminate pathogenic fungi, weed seeds, and nematodes. Sanitation by fumigation prevents unnecessary introduction into the seedbed of pathogenic fungi, insects, and other pests. If pine needles, etc., are used for mulch, fumigate under tarp with methyl bromide 98% - chloropicrin 2% or methyl bromide 67% - chloropicrin 33% at the rate of 1 pound per cubic yard of mulch. Aerate the mulch at least 48 hours before it is applied to nursery beds.

FERTILIZATION

Fertilizer composition, rate, timing, and application methods can have adverse or beneficial effects on disease problems. Sub-optimal rates, inadequate formulation, and improper use of fer-

tilizer often results in seedling stunting, yellowing, poor root development, and mortality. Excess nitrogen application in early spring in soils deficient in calcium and phosphorus may increase seedling damage by damping-off fungi. Excessive levels of phosphorus (200 lbs. available P_2O_5 per acre) will inhibit both naturally occurring and artificially inoculated ecto- and endomycorrhizae on conifer and hardwood seedlings.

SANITATION

Sanitation is an important practice in nursery pest management to prevent the spread of pest problems within the nursery and to field plantings. The practice includes roguing diseased seedlings and weed species in seedbeds. Existing susceptible windbreak species may require elimination to avoid build up of fungus inoculum and insects. Weed-free riser lines and fence roads will help reduce the spread of weed seeds, fungi, and insects into the nursery bed.

SEEDLING GRADING AND CULLING

Grading of seedlings before packing will minimize the transport of pest-infested seedlings to the planting site. Conspicuous root, stem, and foliage diseased seedlings should be culled in the packing shed. Particular seedling grading and culling efforts should be afforded potentially significant pest problems, such as the root rots (charcoal - Macrophomina phaseolina, cylindrocladium - Cylindrocladium spp., and phytophthora - Phytophthora spp.) and southern pine fusiform rust (Cronartium quercuum f. sp. fusiforme) (Rowan, Cordell, and Affeltranger 1980). Although it is costly, nursery managers who have eliminated seedling grading in packing sheds should consider reinstating this practice when severe pest problems appear.

BIOLOGICAL AGENTS

Biological techniques represent one of the most desirable INPM practices, but effective pest control procedures are very limited for nursery production. Perhaps the best example of biological application in nurseries involves the artificial inoculation and/or management of selected mycorrhizal fungi to increase seedling quality (Cordell and Webb 1980).

Most micro-organisms in the soil are either saprophytic or nitrification agents. Some microorganisms are antagonistic or competitive with soil-borne pathogens. Without sufficient populations of these beneficial microflora, organic matter decomposition and nutrient fixation are greatly impeded. Most of the organisms are the pioneer colonizers of recently fumigated soil. Their presence is essential for the conversion of ammonia nitrogen to the nitrate form, which can be used by seedlings.

CHEMICAL TREATMENTS

Chemical treatments involve a variety of pre- and post-planting pesticide applications. Although the use of pesticides is considered a significant component of INPM, pesticides should be used only when other INPM procedures are not available or have failed to give satisfactory control of pests.

SOIL FUMIGATION

Soil fumigation is the most effective chemical control technique for a variety of soil-borne nursery pests, including soil fungi, insects, nematodes, and weeds. The most effective soil fumigants are the methyl bromide-chloropicrin formulations. The methyl bromide 67% - chloropicrin 33% formulation is most effective in controlling root pest problems and certain weeds and grasses, such as nutsedge. Additional benefits from thermal energy can be obtained by allowing the tarp to remain on the seedbed after fumigation for 10 to 14 days or until the beds are prepared for planting.

SEED TREATMENT

In southern nurseries, most pine seeds are coated with Thiram fungicide-latex sticker to retard damping-off and repel birds. Thiram at the rate of 2 pounds per 100 pounds of seed is commonly used. For the control of fusiform rust in southern nurseries, the systemic fungicide triadimefon (Bayleton) is presently being used as either a liquid seed soak or dry powder coating to protect the young pine seedlings during the first few weeks following emergence (Rowan and Kelley 1983).

PROTECTIVE FOLIAGE SPRAYS

There is often a need for protective foliage sprays to control foliage diseases and insects on both conifer and hardwood seedlings (Smyly and Filer 1973). However, only a relatively few chemicals are available for effective and practical control of foliage pest problems. Effective control of foliage diseases requires complete and continuous coverage of the susceptible foliage during the fungus infection period when using a protective contact fungicide. However, effective control of fusiform rust can be obtained with reduced applications (i.e., 3 to 4 well-timed sprays) of the systemic fungicide triadimefon (Rowan and Kelley 1983).

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The USFS Reforestation Improvement Program[1]

W. J. Rietveld, Peyton W. Owston, and Richard G. Miller[2]

Abstract.--The program applies state-of-the-art equipment and methods to input weather, culture, growth, quality, handling, and field data into a computerized database at each Forest Service nursery. The ultimate goals of the program are to increase efficiency, improve reforestation success, and lower costs.

INTRODUCTION

The Reforestation Improvement Program (RIP) is a combined effort of the three divisions of the USDA Forest Service -- National Forest System, Research, and State & Private Forestry -- to improve nursery seedling quality and plantation survival and growth. The concept is to use state-of-the-art data logging and computer technology to monitor selected seedlots and determine the relationships among environmental conditions, nursery culture, seedling handling, seedling characteristics, and performance after outplanting. This information will be used to refine nursery and reforestation practices, develop a continuing quality control system, and identify knowledge gaps that require research.

Following the Seedling Quality Workshop at Oregon State University in 1984, representatives from the three divisions of the Forest Service discussed the agency's nursery program and the research needed to improve the production of quality bareroot stock. In January 1985, a team of nursery managers and research scientists developed a draft proposal to implement RIP. The final proposal was approved, all 11 Forest Service nurseries agreed to participate, and plot establishment got underway by spring 1986. This paper describes the objectives, procedures, and current status of the program.

JUSTIFICATION

RIP was begun at this time for several reasons. The National Forest Management Act of 1976 requires that the successes and failures in our reforestation program be clearly documented and reported to Congress. Responsibility for successful reforestation has been included in line officers' performance standards. We are making more detailed evaluations of plantation survival and growth, and the results of these evaluations have dramatically increased the visibility of our reforestation program. The "Productivity Improvement Analysis of Reforestation" report published in 1983 states that a 10-percent reduction in reforestation failures in the National Forest System would save $2,624,000 annually and that a 50-percent reduction would save more than $13,000,000 annually. Assuming at least a 10-percent improvement in reforestation success, the program is easily justified on a purely economic basis. This is, of course, desirable, but we feel that the public image and professional reasons for improving reforestation success are even more important.

MAKING A CASE FOR MONITORING

Quality monitoring is done in most industries where market competition, liability, and reputation are important factors. In our "industry", the reasons for monitoring are (1) our desire to refine and improve, (2) our pride and reputation, and (3) our accountability. Beyond these compelling reasons, monitoring is impetus for professional growth. Without recording our inputs and their effects, our expertise grows slowly, because we have no clear records of the factors that contributed to our successes and failures. With monitoring implemented we can learn from both our successes and our failures, and readily pass that expertise on to our associates and successors.

Many plantation failures are difficult if not impossible to explain with the data presently

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[1]Paper presented at the Intermountain Forest Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

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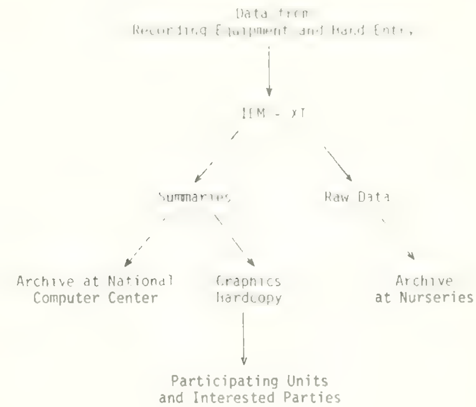
collected. We simply do not know if the problems are occurring at the nurseries, during shipping and handling, during planting, or if they are due to site factors or lack of seedling adaptation. As always, more research is needed to provide answers, but research may not be enough. Presently, the minds of experienced nursery managers and foresters are the databases that hold the wisdom gleaned from years of experience. Two unavoidable problems with this tradition are (1) the memory is volatile, and (2) the databases eventually transfer or retire. To progress from here, we need to develop computerized databases to store the volumes of existing and future data and efficiently put them at our disposal. Once a fairly complete database is developed for each nursery, and research has adequately filled in the important gaps in our knowledge, we will be in a position to attain higher level goals such as: (1) tailoring culture to unique conditions within nurseries and to individual species and seedlots, (2) identifying and manipulating critical factors that most affect planting stock quality, (3) developing an effective system to evaluate planting stock quality and predict field performance, (4) developing planting stock and site preparation prescriptions for individual sites, and (5) developing computer models for the entire reforestation process.

Some of the latest developments in reforestation science illustrate these points. There is a trend towards specific nursery culture of individual seedlots. Jenkinson (1980) has developed time windows for lifting several major timber species and specific seed sources at individual nurseries. Lifting seedlings outside these windows results in reduced survival and growth, and in the worst case, plantation failure. The Weyerhaeuser Company[3] has led the way in growing seedlings by family (seed collected from a clone in a seed orchard), observing growth response to cultural treatments, and grouping families with similar growth into "response groups". Cultural treatments are then tailored to each "response group" to grow seedlings to desired specifications. This increasing sophistication brings increasing complexity and the need for more detailed record keeping, a task that computers can help us with nicely.

PARTICIPANTS AND ORGANIZATION

All 11 Forest Service nurseries are participating in the program. The nurseries are the center of RIP and the principal benefactors. The initial level of commitment at each nursery is to monitor three successive crops of planting stock of two seedlots of one species, and to establish two field plots on different sites.

The following organizational structure was developed for RIP in order to maintain communication and continuity:



A national steering committee monitors the overall program and modifies it as necessary. The program coordinator facilitates installation of the monitoring system, and implementation of data collection, summarization, and archival. A scientific analysis team (SAT) was created to select appropriate seedling measurement equipment and techniques, develop data collection and analysis procedures, and provide feedback and recommendations to individual nurseries. The team will evaluate the data from a research perspective and identify specific problem areas that need additional research.

Pathologists from the participating Regions will conduct pathogen and mycorrhizae analyses. National Forests and Ranger Districts interested in participating in the outplanting phase were identified before specific seed sources were selected for monitoring. The program has also arranged for a local research scientist to provide guidance for each nursery, a technician available by phone to provide support and spare parts for instrumentation problems, a software developer to prepare specialized methods to collect, summarize, graph, and archive RIP's data, and a technician to help with data processing.

EXPECTED BENEFITS

Benefits will increase each year as we monitor new seedlots, encounter different weather conditions, modify cultural practices, and accumulate information on field performance. Expected short- and long-term benefits are as follows:

Short-term (1 to 5 years)

1. Installation and implementation of state-of-the-art equipment and methods at the nurseries to monitor weather, culture, growth, quality, handling, and field variables, and efficiently summarize and retrieve the data on a computerized database at each nursery.

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[3]Personal communication with Dr. William C. Carlson, Tree Physiologist, Weyerhaeuser Co., Southern Forestry Center, Hot Springs, AR 71902.

2. Development of a standardized system for collecting and analyzing nursery data to facilitate interchange of information and technology among nurseries, research units, and National Forests.

3. Increased awareness of seedling biology through tracking of seedling performance from seed to site.

4. Identification of stages in stock production, handling, shipping, and planting where quality is lost, so that nursery managers, foresters, and researchers can focus their efforts on the most critical areas. Some immediate improvement in reforestation success is expected from recognizing and correcting conspicuous problems.

5. Improved communications between nursery managers, field foresters, and researchers, eventually developing feedback linkages between these groups based on common goals.

6. Improved cultural and handling methods in the nursery by utilizing the database to aid decisions on when to perform certain practices, and to document the effects on seedling quality and performance.

Long-term (5 years and longer)

1. Significantly increased and more consistent tree survival and growth after outplanting, with fewer failures and replants, and lower reforestation costs. We should see increased efficiency through the entire reforestation process.

2. Development of specific cultural regimes to match seedlots and seedling characteristics to individual sites, thus utilizing the full potential of each site.

3. Improved nursery practices and knowledge of the relations between stock quality, site conditions, and field performance will improve our ability to predict tree survival and growth on a variety of sites and optimize the cost of stock production.

4. Development of a flexible quality control program for individual nurseries that can be continually refined. Seedling production will gradually shift from an art to a science, enabling nursery managers to manipulate numerous variables and consistently grow seedlings to target specifications.

ESTABLISHMENT OF NURSERY PLOTS

Each nursery is monitoring two different seedlots of at least one of the major species that it produces; five western nurseries are monitoring ponderosa pine, four western nurseries are monitoring Douglas-fir, one northern nursery is monitoring red pine, and one southern nursery is monitoring both loblolly and longleaf pines. Ten nurseries made their initial sowings in 1986, and one nursery began this year.

The same seedlots of each species will be sown for 3 consecutive years so that they will be grown under a variety of weather conditions. Standard cultural practices will be used in the 100 feet of seedbed that will be sown for each seedlot and year. All the sowings will be clustered as close together as possible so that they are in similar soil and subject to similar weather conditions.

ENVIRONMENTAL MEASUREMENTS

Electronic recording weather stations are the heart of the environmental monitoring phase of RIP. One station is located on a permanent site at each nursery to collect baseline weather data. A second station is located near the test seedbeds so that sensors can monitor the weather and soil conditions to which the seedlings are actually exposed. Conditions measured are: air temperature at 1.5 m above ground and at the seedling canopy level (20 cm), relative humidity, precipitation and irrigation, wind speed and direction, incoming radiant energy and photosynthetically active radiation, soil surface temperature, and soil temperature and moisture in the seedling rooting zone. The recorder scans the sensors every 5 minutes and records the hourly maximum, minimum, and average temperatures; average humidity, radiation, and wind direction; average and maximum wind speed; and total precipitation or irrigation.

One-time measurements of soil physical characteristics were made in the test beds, and periodic measurements will be made of soil fertility, pathogen levels, and quality of irrigation and runoff water.

Environmental conditions that the seedlings are subjected to during lifting, processing, shipping, and planting will be carefully monitored. This will include factors such as root exposure time; temperatures during grading, storage, and shipping; and number of times the seedlings are handled. Temperatures during storage and shipping will be measured by another recording device, a Datapod[4], that will be placed inside packing bags to record temperature hourly until the seedlings are removed from the bags for planting.

These environmental and history data will be used in graphics, in correlations with seedling growth in the nursery, and in interpretations of observed responses to culture.

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[4]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

CULTURAL PRACTICES

All cultural activities performed on the test seedlots will be documented by date and specific treatment. Any errors and unusual occurrences will be noted. Cultural practices include seed stratification, sowing, mulching, thinning, weeding, fertilization, irrigation, pesticide application, shoot and root pruning, and wrenching. No experimental treatments will be applied to the monitored seedbeds, but if any practice is changed nursery-wide during the program, the modified practice will also be instituted in the RIP seedbeds. This information will be used primarily for interpreting results rather than for making specific correlations with growth and performance.

SEEDLING MEASUREMENTS

Despite all the high-tech gadgetry, seedlings are the main focus of the program. We will examine them outside and in, i.e. morphologically and physiologically, and correlate their development, growth, and condition with (1) nursery environment and culture, and (2) field performance.

Monitoring will begin with establishment of history plots at time of sowing to determine germination rates and plantable seedlings as a percent of seeds sown. Random samples of seedlings in the seedbeds will be repeatedly measured to determine height and diameter growth, bud activity, and foliage color; and separate samples will be destructively measured to obtain root growth. We will monitor plant moisture stress during dormancy induction and mineral nutrient status in the fall when the seedlings have stopped growing.

Several measurements and tests will be done when seedlings are lifted: morphological (external) characteristics will be measured -- height, stem diameter, bud length, dry weight, and foliage color; and physiological (internal) conditions will be assessed by several tests -- mineral nutrient status, carbohydrate reserves, root growth potential, cold hardiness, and stress resistance.

Carbohydrate and mineral nutrient analyses require sophisticated equipment and will be done by private or university laboratories. The root growth potential, cold hardiness, and stress tests, however, will be done at the nurseries. This will be more economical, and the seedlings will not be subjected to storage and shipping that might alter their physiology. The main reason for doing the tests on site, however, is to give nursery personnel greater familiarity with the specialized measurements and tests of planting stock quality.

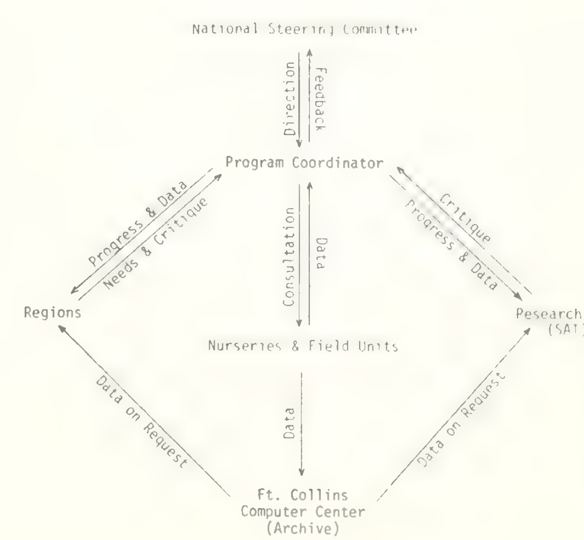
ESTABLISHMENT OF FOREST PLOTS

The payoff is, of course, field performance of the seedlings. It makes no sense to grow high quality seedlings if they are going to fizzle after outplanting, or disappear into the unknown. Therefore, we have asked various Forest Service Ranger Districts to establish and monitor test plantations. Planting stock from each nursery will be outplanted on two forest sites; each will have an electronic weather station identical to those used at the nursery. The sites will be partially planted in each of 3 consecutive years. Depending on the compatibility of the monitored seedlots with the seed zone of each forest site, some test plantations will be planted with both seedlots and others will have only one. Only 200 seedlings per seedlot will be planted and tracked per site, so it will not be a heavy workload. Site preparation will be the biggest problem on many sites because the program requires that approximately one-third of each site be planted in each of 3 consecutive years, but with site conditions as similar as possible. We will work individually with each National Forest to develop a planting plan that is operationally feasible, statistically valid, and consistent with RIP plans and objectives.

As with the nursery phase, environmental conditions, handling, seedling characteristics, and seedling performance on the field plots will be recorded for later analyses and correlations. We are working with the National Forests this year to make sure preparations are made for installing forest plots during the 1988 planting season.

DATA HANDLING AND ANALYSIS

Data collection and analysis are critical parts of RIP. The general plan for data flow is as follows:



Each nursery was provided with a microcomputer, electronic weather stations and data reader, datapods and reader, a portable data collector, and software to receive the transmitted data, automatically summarize it, and archive it.

Weather data are stored in a removable memory pack that holds 32,000 bits of information (64 K packs are now available). The packs are changed once a month. A full pack is plugged into a special reader that transmits the data to a microcomputer where a communications program captures it and stores it as an ASCII file. The pack is then erased and reused. The same scheme is used to retrieve package temperature data stored in the Datapods. The scheme designed for the portable data collector to collect seedling data and transmit it to the computer for processing is covered in more detail in a separate paper (Rietveld and Ryker 1988).

ASCII files containing the data are imported into preformatted spreadsheets where standardized data summaries and graphs are automatically generated through the use of macros. Graphs of weather data show monthly summaries of: incoming radiant energy, photosynthetically active radiation, precipitation, percent relative humidity, air temperature at 1.5 m, air temperature at 20 cm, wind speed, wind direction, soil surface temperature, soil temperature at 15 cm, and soil moisture at 15 cm. Graphs of seedling data are generated showing: seed germination, height growth, caliper growth, root growth, and bud activity, all in relation to time, air temperatures, soil temperatures, soil moisture, and solar radiation. Parameters such as growing degree days, chilling hours, and potential evapotranspiration are also calculated. Raw and summarized weather and seedling data from the nurseries and forest sites are archived at the nursery, and summarized data are archived at the National Computer Center at Fort Collins, CO, for safekeeping and sharing with approved interested parties.

INTERPRETATION OF DATA

Nursery managers can manipulate the data and generate other summaries and graphs as they wish. Such information will be useful in planning and evaluating day-to-day nursery operations and making decisions, as well as building a strong database for continuing quality control.

The data will also be evaluated by RIP's scientific analysis team. Because RIP is not a controlled research experiment, the opportunities to apply statistical analyses will be limited. Initially, the team will be restricted to making inferences based only on observations; after data are collected for three crops of planting stock (fall 1990), it will be possible to apply some limited statistical analyses. The general types of comparisons that will be made are as follows:

<u>Nursery</u>		<u>Nursery</u>
Weather History Culture	<u>vs</u>	Seedling growth Seedling morphology Seedling physiology
<u>Nursery</u>		<u>Field</u>
Seedling morphology Seedling physiology Processing & handling	<u>vs</u>	Seedling cond. on arrival Seedling surv. and growth
<u>Field</u>		<u>Field</u>
Site weather Site history Pest problems	<u>vs</u>	Seedling surv. and growth

Scientific analysis is expected to take the following progression:

Observations

1. <u>Evaluate field performance</u> -- if a seedlot does poorly at one site and not at the other site, look at site data; if a seedlot performs poorly on both sites, look at both site and seedling quality data.

2. <u>Evaluate repeatedly measured variables</u> (seedling height, caliper, root growth, foliage color, bud activity, plant moisture stress, root growth potential, and carbohydrate reserves) -- the only thing that can be done early in the program is to flag anything that looks suspect, since we don't know what constitutes a normal level for the variables at each nursery.

3. <u>Contrast variables</u> -- note differences in selected variables between seedlots, sites, and nurseries (for the same species). Graph selected variables for all nurseries growing the same species (ponderosa pine or Douglas-fir) to become familiar with basic nursery and seedlot differences.

4. <u>Evaluate models and indices</u> -- evaluate the usefulness of various models to relate weather variables to seedling growth and phenology (e.g. degree hours with seedling growth in the nursery, chilling units with cold hardiness, etc); and evaluate the ability of existing stock quality indices to predict seedling quality and performance.

5. <u>Evaluate unusual events</u> -- evaluate the effects of any disasters or any unusual weather events, contrasting nursery practices and field operations.

Statistical Analyses

1. <u>Correlations</u> -- by fall 1990, we will have first-season performance data on three crops of planting stock on each of two forest sites, giving a sample size of six for each seedlot. Correlation analysis of planting stock quality

variables (seedling height, caliper, dry weight, root growth potential, carbohydrate reserves, etc.) with performance variables (survival, height growth, caliper growth, etc.) will be barely possible becaue of the small sample size.

2. Regression analyses -- simple linear regression will be possible after we have data for three crops of stock. However, the real power of regression analysis cannot be realized until a sufficient range of data points is available, which will come with additional years of monitoring. To some extent, datasets can be expanded by including data from more than one seedlot and nursery (for the same species), but only if they satisfy certain tests for common regressions.

3. Develop standards and indices -- with sufficient data, application of single and multiple regression analyses will allow inferences of cause and effect relations in the nursery, between the nursery and the field, and in the field. Consistently significant relations may be used to develop indices that can be conveniently applied to predict response. In the process, we will evaluate, modify, and adapt existing indices and models for individual nurseries.

SUMMARY

The USDA Forest Service has undertaken an ambitious program to accelerate the transition of nursery management and reforestation from an art into a science. The goals of the Reforestation Improvement Program are to (1) supply each nursery with state-of-the-art equipment and methods for recording weather, cultural, and seedling variables; (2) develop a monitoring system that links the nursery with the field and provides a system for feedback; and (3) develop a computerized database for each nursery that is easily accessed, is interactive with nursery management, and will eventually guide refinements in nursery culture and field operations. The real value of the database will grow in direct proportion with the quality and completeness of the data put in, and with time. There will be only a limited ability to extract information from the databases during the first few years; mostly we will benefit professionally by increasing the depth of our documentation and awareness. The real payoff comes with the accumulation of data over years. Eventually, with the assistance of research, we will develop culture/quality/performance relations for individual nurseries, establish appropriate stock standards, and greatly improve our ability to predict seedling performance on a variety of sites.

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Government vs Private Nurseries: The Competition Issue[1]

Thomas D. Landis[2]

Abstract.--The issue of competition between government and private forest tree seedling nurseries has been politically sensitive in recent years. An analysis of both the different types of nurseries and seedling markets provided an information base. The question of competition in the forest nursery business can be analyzed in terms of seedling price and quality in the open and closed seedling markets. Although some degree of competition between government and private nurseries is inevitable, a number of positive approaches are presented which can overcome or prevent serious problems.

INTRODUCTION

Over the past decade there has been increasing concern over the issue of competition between government and private forest tree seedling nurseries. Advocates of nursery privatization have gone as far as introducing legislation both on the federal and state level to eliminate government-run nurseries. A recent informal survey was circulated to state forest nursery managers in the west to determine the extent of the government/private nursery competition problem. Survey responses indicated that all western nursery managers were concerned about the nursery competition issue, and that there was a serious problem in 29% of the states at the present time.

Actually, the government/private nursery controversy is not a new topic, but has surfaced several times in the past as evidenced by an editorial cartoon that appeared over 45 years ago (Figure 1). This cartoon was generated by the introduction of legislation that proposed the abolishment of the California State Tree Nursery at Davis. Apparently, the newspaper editors considered closing the state nursery a foolhardy proposition.

Responding to this widespread concern, the organizational committee for the 1987 Intermountain Forest Nursery Association meeting decided to explore the nursery competition topic. Rather than have formal presentations expressing divergent, and sometimes polarized, points of view, an informal format was designed that encouraged communication and discussion. The facilitated small-group discussions generated a

Figure 1.--The government/private nursery controversy as depicted in the Sacramento Bee, April 4, 1941 (courtesy of G.A. Ahlstrom)

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[1]Paper presented at the Intermountain Forest Nursery Association meeting, Oklahoma City, Oklahoma. August 10-14, 1987

[2]Thomas Daniel Landis is Western Nursery Specialist, USDA-Forest Service, Pacific Northwest Region, Portland, Or.

comprehensive list of ways in which all forest seedling nurseries can work together to resolve, and possible prevent, confrontation. This article was written to serve as an introduction to these small-group discussions.

The purpose of this article is to provide perspective on the government/private nursery controversy, which will hopefully lead to an increased understanding of the issues involved and some mutually acceptable solutions. Before we can analyze the government/private nursery issue, however, both the types of nurseries and the types of markets in the forest tree seedling business must be defined.

TYPES OF FOREST NURSERIES

Nurseries that grow woody plant seedlings can be organized into four classes:

1. Federal nurseries - these government nurseries, such as those operated by the USDA-Forest Service or USDI-Bureau of Indian Affairs, were established to produce seedlings for government forest lands. Most are prohibited from directly selling seedlings to other forest land holders or on the ornamental seedling market.

2. State nurseries - nurseries operated by state governments produce seedlings for a wider range of markets, including state forest lands, but also sell seedlings for conservation purposes on private forest lands. They are generally prohibited from selling seedlings for ornamental purposes.

3. Industrial nurseries - some of the larger forest industries have nurseries which produce seedlings for their own lands but also sell seedlings on the open market, including ornamental sales.

4. Private nurseries - these nurseries are operated by private individuals or corporations and sell seedlings for all purposes in any market.

TYPES OF MARKETS FOR FOREST TREE SEEDLINGS

There are two types of markets in the forest nursery business:

1. Open markets - seedlings can be purchased without restriction from any supplier. The open market consists of both large and small landowners who purchase seedlings from state, industrial, or private nurseries for a variety of conservation planting purposes.

2. Closed markets - customers are obliged to purchase their seedlings from one supplier. Examples of closed markets can be found in both the government and private sectors. Tree seedlings for most federal forest lands are traditionally purchased from an associated government forest nursery. Some timber companies have also developed nurseries to produce seedlings for their own lands.

Another related, yet slightly different, market for woody plant seedlings is the ornamental seedling market which consists of seedlings sold for landscaping rather than conservation purposes.

DEFINING AND EXAMINING THE COMPETITION ISSUE

According to Webster's Dictionary, competition is defined as "the effort of two or more parties acting independently to secure the business of a third party by offering the most favorable terms". The question of competition, therefore, hinges on the phrase "most favorable terms" which, in the tree seedling nursery business, breaks down into 2 components: price and quality. These two factors can be analyzed in both the open and closed seedling markets:

The Pricing Issue in the Open Market

Most private and forest industry nurseries set their seedling prices based on demand in the open seedling market. There are basically two pricing structures in the open market: "spot market" and "contract". Spot market prices are established near the end of the crop rotation and are dependent on the traditional economic forces of supply and demand. Contract seedling prices are set at the time of contract award, before the seed is even sown, and are controlled by the terms of the specific contract. Most smaller landowners purchase their seedlings at the spot market price, whereas larger landowners and government nursery organizations normally purchase open market seedlings by contract.

Many state government nurseries have traditionally kept their seedling prices low to stimulate tree planting for conservation purposes. However admirable this pricing policy may be, it actually fuels competition because it keeps seedling prices below the open market value. Private nursery managers have a valid case when they contend that these artificially-low priced seedlings may lure potential customers away from their nurseries. One solution to the price issue is to set state nursery prices higher than private sources such as is being done by the California Division of Forestry. Using the dictionary definition, competition between state government and private nurseries would be eliminated under this pricing policy.

The Quality Issue in the Open Market

Although there has been much discussion and interest about seedling quality, this attribute remains an elusive property. Much research has been done on this subject, but there is still no standard definition or procedure for determining seedling quality.

Seedling quality is also variable from region to region. Because of vast differences in outplanting site conditions and in the genetic constitution of a seedling, an acceptable seedling from one geographical area may not survive in another. This is often due to the fact that seedlings adapted to lower elevations and milder climates are less cold-hardy than local species and can be damaged, or even killed, when planted in areas with harsher winters.

The use of source-identified, locally-adapted seedlings is absolutely essential in conservation plantings to insure that the seedlings will survive and grow after outplanting. The use of source-identified seed is well supported in the scientific literature although it is conveniently overlooked in some unprofessional nursery transactions. The question of whether locally-grown seedlings are better adapted to local planting sites is not as clear, but this practice has been traditionally emphasized by foresters in climatically-diverse areas like the Intermountain West. This "source-identified, locally-adapted" concept is critical in the forest nursery industry because the general public might be tempted to buy tree seedlings based on general appearance and price rather than quality.

The need for source-identified, locally-adapted stock is not as critical to many ornamental tree seedling growers because they deal with "cultivars" that are selected for foliage color or some other ornamental trait. Because they are planted in landscape situations where environmental stresses are minimal, cultivars can be produced by many different nurseries and are normally shipped over wide geographical areas.

Seedling quality is also a function of what happens to a seedling after it is harvested from the nursery. Many nurseries can grow reasonably healthy seedlings, but are not equipped to properly handle seedlings through the storage and distribution phase. Most larger forest nurseries in the west, both government and private, have well-designed seedling storage facilities and handling procedures. In some states with smaller seedling programs, however, government nurseries are often the only ones who have properly designed seedling storage and delivery systems - facilities like refrigerated storage and distribution vehicles that take seedlings out to the customer (e.g. "Trees on Wheels" programs run by several western state forestry organizations).

Seedling Price and Quality in Closed Markets

Many nurseries that produce seedlings for their own use generally set prices based on production costs, rather than open market value. The price of federal government nursery seedlings is annually computed based on the cost of production, and therefore seedling prices reflect both variable costs like fertilizer and fixed costs such as machinery depreciation. In the past, because federal nurseries sold seedlings to the closed government market, the question of price competition with private nurseries was somewhat irrelevant. Now that private nurseries are producing contract seedlings for federal forest lands, however, the price issue becomes more meaningful and competition is possible.

One of the most important issues concerning the future of government seedling contracts with private nurseries revolves around the issue of seedling quality: the proven ability of private nurseries to supply quality seedlings on a sustained basis.

1. Proven ability - Many private nurseries have shown that they have the ability to produce quality forest tree seedlings, although a few nurseries with first-time contracts have not performed satisfactorily. Established nurseries that have demonstrated a good seedling production record, however, can expect to continue to receive government contracts.

2. Quality seedlings - Although some private nurseries have shown that they can produce good quality seedlings, government foresters have had some serious problems with private nursery contracts. Many of these problems have centered around contract seedling specifications: one of the relevant questions here is whether anyone can really write contract specifications that define something as complex and controversial as a "quality seedling".

There is also a tendency among many government contracting officers to think of seedlings as inanimate production units - "widgets". These non-biologists mistakenly think that quality tree seedlings are like any other contract item and can be routinely produced by anyone with the proper equipment. On the contrary, the ability to consistently produce a high-quality forest tree seedling crop requires technical expertise and cultural ability seasoned by experience, in addition to a suitable nursery facility.

The quality issue is not restricted to government contracts with private nurseries. Government nurseries also have problems with seedling quality from time to time, yet government foresters are often discouraged from purchasing seedlings from other sources.

3. Sustained basis - This issue is a "catch-22" and must eventually be resolved over time. Unfortunately, many government agencies only issue single-year seedling growing contracts and award them to the lowest bidder. Individual private nurseries have no way to be certain that they will have part of the government seedling market from year to year. Because of this ephemeral demand, many private nurseries have no way to prove that they can fulfill government seedling needs on a sustained basis.

The federal government has been purchasing more seedlings from private nurseries in recent years. As an example of this changing policy, Region 6 of the USDA-Forest Service (Oregon and Washington) has gradually increased its contracting requests for privately-produced tree seedlings. The number of private nurseries with Region 6 seedling production contracts has risen from 6 in 1984 to 10 in 1987, and the percentage of the total seedling orders filled by private nursery contracts has increased from 8 to 14% over the same time period.

CONCLUSION: SOLUTION THROUGH COOPERATION

The solution to the problem of government/private nursery competition must eventually be resolved through the cooperative efforts of all the parties involved. As is true in animal ecology, competition between two different organisms rarely leads to direct conflict, but rather to some socially-acceptable modification in the behaviour of each individual.

True to this ecological adage, a spirit of cooperation was evident in the small-group discussions during the government/private nursery session at this meeting. The opening statements of many participants reflected divergent viewpoints but, as they heard the positions of other group members, traditional barriers began to vanish. Two of the most significant observations to come out of these discussions were:

1. The government/private nursery competition issue is much more complex than most people originally thought. As is often the case, there are no simple solutions and increased communication between all concerned parties is necessary to increase mutual understanding.

2. The situation varies considerably from one region of the country to another. What is true in the Pacific Northwest does not necessarily apply to the Great Plains or the South. Because of this regional variation, the problem should be treated on a local, rather than a national, basis.

As a product of these enlightening discussions, each group developed a positive list of ways in which all nursery managers can cooperate and resolve potential conflicts in the future (details of this exercise are reported in Session Two of the following article). Some of the more noteworthy ideas were:

1. Establish regional nursery advisory boards composed of representatives from both the public and private sector. The activities of these advisory boards would include planning and coordination, establishment of seedling quality standards, and conflict prevention.

2. Stimulate better communication between all types of nurseries to minimize potential conflicts and take advantage of opportunities to cooperate. This could include regular visits to other nurseries, and participation in local nursery associations.

3. Promote use of private nurseries for government seedling procurement, not only for excess needs, but as part of the annual program.

4. Each government nursery should develop a formal nursery policy that spells out their operating guidelines and how they relate to private sector nurseries with respect to potentially harmful practices like seedling marketing and surplus seedling sales.

The author would like to express his appreciation to Steve Hee of Weyerhaeuser Company, Jerry Ahlstrom of the California Department of Forestry, and to Dick Miller and Paul Forward of the USDA-Forest Service for providing valuable insight into this important issue and taking the time to review the manuscript.

Working Group Sessions on Communications and the Government/Private Nursery Issue[1]

Kurtis L. Atkinson[2]

Abstract.--Facilitated working group sessions were held to develop lists of actions to improve communication and cooperation among nurseries in the Great Plains, and reduce the conflict between the government and private nursery sectors. These actions may be used as a starting point to improve working relationships between all nurseries.

Session I: Communications

A working-group exercise was held to identify areas in which forest nurseries could cooperate, communicate and share ideas. The attendees were divided randomly into four groups, and led through the process by a trained facilitator. It was structured as follows:

Purpose

Find ways to increase communication and cooperation between forest nurseries.

Desired Outcome

A list of opportunities for increased cooperation and communication between forest nursery organizations.

Process

Nominal Group Technique

Results

The results from the four groups follow. No attempt was made to consolidate these lists. The asterisks (*) denote items given a high priority by each group and were the only ones presented to the entire assembly.

Conclusion

It is hoped these results will stimulate interchange between nurseries, and perhaps serve as the basis for a formal method of exchanging and sharing information. The participants themselves must take the initiative to further develop these ideas into a workable method to take advantage of the opportunities which are evident.

<u>Group I</u>

* 1. List of tree seed, seedlings and surpluses
2. Political issues facing nursery business
3. New cultural practices
* 4. Share information on pesticides and new insects & diseases
* 5. Co-op seed collection
6. Lists of salvage or replacement equipment
7. Tested modifications in nursery equipment
8. "Bugs & Cruds" problems and solutions
9. Interacting with locally operated nurseries
10. Quick response on first time problems

[1]Results derived from working group sessions at the 1987 Intermountain Forest Nursery Assoc. meeting [Aug. 10-14, 1987, in Okla. City, Okla.].

[2]Kurtis L. Atkinson is Assistant Director of the Forestry Division of the Okla. State Dept. of Agriculture, Okla. City, Okla.

11. Use of by-products, recycling, etc.
* 12. Improvements in safety
13. Bareroot precision sowing
14. Facilities that may be available (contract/otherwise)
15. Species list
* 16. Nursery practices which enhance outplanting survival
17. Human resources available for consultation
18. Alternative labor sources /employment opportunities
19. New insect & disease information
20. Development of national grading standard
21. Seedling testing
22. Packing containers (type/cost)
23. Germinating problem species
24. Effective control of weeds
25. Improving customer relations
26. Odd species seed availability
* 27. Improved seed and seedling storage
28. Good tiers (taers)
29. Bareroot vs. containers
30. Re-cycling to save costs; tubes, boxes, etc.
31. List of suppliers, costs, bulk ordering
32. Cooperative studies of cultural practices
33. Results of seedbed densities
34. Sample contracts
* 35. List of current nursery studies
36. Grading & handling of bareroot stock
37. Outplantings, contracts, contractors, equipment
38. Bookkeeping practices
39. Research & observation of new methodology
40. University resources (testing person power)
* 41. Innovative ways for seed stratification
42. Accurate forecasting needs & wants (market data)

Group II

* 1. Surplus/shortages of seedlings & seed
2. Quarterly recaps of productivity and activities; a procedure for dissemination
* 3. Educational program, i.e., training of staff, foremen, & nursery personnel (management, computers, etc.)
* 4. Seed collection, seed source i.d., purchasing seed, cooperation
5. Pooling of resources to promote more intensive tree improvement program between states
6. Incentives to increase productiveness of seasonal labor
7. Consolidated purchasing of materials and services
8. Interagency, state and regional cooperation on I&E
* 9. Mechanical innovations/developments
10. Sharing of equipment and supplies in the event of breakdowns
11. Cooperative growing of seedlings
12. Personnel needs
13. Better feedback on plant material success from the field
* 14. Information system that is applicable to nursery management and administration (principally PC software)
15. Exchanging expertise in specialized area
16. Equipment specification and performance
17. Vendor listing by categories and region
18. Join together to market products
19. Provide cooperative R&D on problems and opportunities that are common to nurseries
* 20. Information exchange of specific cultural situations and problem solving, including: pesticides, pests, nutrients, soil/pesticide interactions, innovations, seed handling, collection, processing, etc.

Group III

* 1. Day to day cultural and operational tips
2. Record keeping
3. Harvesting techniques
* 4. Who's doing what (research, etc., names of contacts)
* 5. Listing of nurseries, species, capacities, addresses, phone numbers, etc.
* 6. Equipment technology & shared equipment performance information
* 7. New laws relating to chemical use, personnel management, environmental constraints (in understandable form - do's & don'ts)
* 8. Promotional techniques & materials
9. R.I.P. information sharing
* 10. What's and How's in connection with herbicide use
* 11. Inventory: surpluses, shortages & prices
12. Surplus supplies inventory
13. Relate seedling quality to field performance
* 14. Problem alert system
15. Job openings
16. Seed availability - price
17. Techniques of inventory control, sales, and delivery management

* 18. Software needs & availability
19. Methods of packing
20. Cost reduction techniques
21. Evaluation of seed sources for different products

Group IV

1. Success/failure in weed management, herbicides, why?
2. Insect alerts, aphids/hoppers
* 3. What expertise do others have in specific areas?
* 4. Software that others use such as storage & retrieval of cultural and production information
5. Training opportunities
6. Sharing, coordinating, interpreting data
7. Telecommunications network
* 8. How inventories? Accuracy rates, costs, procedures?
9. Calibrating mechanical seed sowers, what accuracy experienced?
10. Combined inventories of spare parts
* 11. What supplies in common and where acquired (boxes, chemicals, etc.) possible coordination of purchasing.
12. Surplus seed and seedlings
13. Surplus equipment
14. Available services (tissue analysis, diagnosis, etc.)
15. Seed sources (especially hardwoods)
16. Comparing germination data
17. Coordinating equipment development
18. Coordinating job opportunities
19. Bulletin board service with telecommunications
20. Seedling packing containers and medium
* 21. Success or failure of plantations
22. What policies or guidelines do others use? (size of seedlings, complaints, many more)
* 23. Success/failure - pest management, fungicides, fumigants, insecticides, why?
24. New materials available for pest control
* 25. What criteria others use to determine seedling quality? Equipment used? Which best to predict field survival?
26. Comparing clean seed yields
* 27. Ideas about formal research and informal trials underway at other nurseries, results.
* 28. Availability and use of climatic data to plan planting schedules and make yield predictions.
* 29. Successes/failures in soils management (pH, fertilization, etc.)
30. Storage temperatures by species.
* 31. What species are others growing? What cultural practices?
* 32. Planting methods, methods of reforestation, equipment, etc.
33. Invite a friend to lunch and share information.
34. Tonight is ladies night in the bar.

Session II:

Government vs Private Nurseries

A second working-group exercise was held to address the government /private nursery issue. The attendees were divided randomly into three groups, each with a trained facilitator and recorder who coordinated the process. It was structured as follows:

Issue

Private sector concerns about competition from publicly operated nurseries.

Purpose

1. Stimulate participants' minds about things they or their organization can do to help reduce concerns about this issue.

2. Document the suggestions of this group of experts, close to the issue, for use by various organizations who may be studying the issue.

Process

Facilitated Discussion

Results

The results from the three groups follow. No attempt was made to prioritize the ideas with-in the groups, nor to consolidate the statements for the conference as a whole.

Conclusions

The result of this session will be provided to the National Association of State Foresters to use during their consideration of this issue. The participants should also take the initiative to further develop these ideas into a workable, cooperative and mutually agreeable plan of action.

GROUP 1

1. Artificially set seedling prices from government nurseries higher than private sector, on state by state basis.
2. States develop a policy statement related to public nursery activities, with private sector participation.
3. Contract with private nurseries to produce stock for use on public lands.
4. Establish a nursery advisory board, with representation from all sectors.
5. Assure selected (certified) seed sources are available to all growers.
6. Public education about the need for quality seed sources, species, quality of planting stock, etc.
7. Regional coordination of nursery policies, etc.
8. Assure private sector is included as an option during public agency technical assistance (CRP).
9. Establish basic standards of stock quality, seed sources, species selection.
10. Public and private sectors should target market areas.
11. Nursery Board act in conflict resolution.
12. Define, clarify and continue to evaluate the need for public nurseries.
13. Public nurseries become more involved in private associations (e.g., AAN, State Association, etc.)

GROUP 2

1. Public nurseries should develop marketing policies with input from private and public sectors.
2. Develop joint promotional/educational effort to encourage tree planting.
3. Develop nursery advisory boards by state/region involving all sectors - public (state & federal) and private.
4. Personal contact with private nurseries for the purpose of information exchange by field and nursery personnel.
5. Sponsor a public nursery inventory surplus list for distribution to local private nurseries for seedlings that are available for sale.
6. Public nurseries should charge their actual production costs (including costs of land and overhead).
7. Utilize private nurseries to provide flexibility rather than expand public nurseries (includes contracting special needs, trading stock, etc.)
8. Develop a positive medium for information/technology transfer promoting cooperative partnerships.
9. State/Federal Forester rep. should belong to State Nursery Assoc.

GROUP 3

1. Increase communication among all groups.
2. Share in each others planning process.
3. Increase supply contracts to private nurseries (state & federal).
4. Moth ball marginal state or federal nurseries.
5. When comparing quality and cost, use the same criteria and accounting procedures.
6. Establish regional advisory boards to address needs and impacts.
7. Moth ball or contract out low demand species.
8. Limit the programs eligible for discounted seedlings.
9. Sales from government nurseries to private nurseries.
10. Study competition issues in other industries. How do they resolve problems?
11. All public nursery managers join their state's nursery association.
12. Have people involved in harvest planning on advisory boards to help predict the future.
13. Separate state and federal issues when talking about alternatives. Separate conflicts/address separately.
14. Show and tell at public nurseries for private nursery managers.
15. Examine decentralized seedling procurement in the federal system.
16. Make sure advisory board members are knowledgable.
17. Make sure spokesmen from private sector are expressing the majority opinion.
18. Standard grading for seedlings.
19. Develop an action plan.
20. Implement.

Minutes of the Annual Business Meeting

The meeting was called to order by Tom Landis at 8:30 A.M. on Friday, August 14.

Old business: The Proceedings of this meeting will again be published as a General Technical Report by the Rocky Mountain Forest and Range Experiment Station, with funds provided by State and Private Forestry, USDA-Forest Service. The last date for papers to be submitted for the Proceedings is October 1, 1987, and target date for publication is January 1, 1988. Send papers to Bob Hamre at the Research Station, or call Tom if you have questions.

New business: The 1988 Intermountain Forest Nursery Association meeting will be held in Vernon, B.C. on August 10-12, 1988. This will be a joint meeting of the Intermountain Nursery Association, the Western Forest Nursery Council, and The Forest Nursery Association of British Columbia. Ralph Huber of the B.C. Ministry of Forests is coordinating the meeting plans and an informational mailing should be distributed this fall. Ralph can be contacted at 604-387-8942 for more information.

The 1989 Intermountain Forest Nursery Association meeting will tentatively be scheduled for either North or South Dakota. More information will be forthcoming as plans develop.

The Intermountain Forest Nursery Association is 27 years old! Marv Strachan, nursery manager emeritus and organizer of the first meeting, has volunteered to develop an archive for the association. He will be attempting to gather a complete set of past proceedings, and index them for easy reference. The end product will be a complete set of all Intermountain Forest Nursery Association Proceedings with a subject index. Tom Landis added that State and Private Forestry supports this project and will attempt to secure financing.

There was no further business, so the meeting was adjourned at 9:00 A.M.

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Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

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United States
Department of
Agriculture

Forest Service

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**General Technical
Report RM-152**

AN ENGLISH-SPANISH GLOSSARY OF TERMINOLOGY USED IN FORESTRY, RANGE, WILDLIFE, FISHERY, SOILS, AND BOTANY

GLOSARIO EN INGLES-ESPANOL DE TERMINOLOGIA USADOS EN FORESTALES, PASTIZALES, FAUNA SILVESTRE, PESQUERIA, SUELOS, Y BOTANICA

ABSTRACT

The English-Spanish/Spanish-English equivalent translations of scientific and management terms (jargon) commonly used in the field of natural resource management are presented. The glossary is useful in improving communications and fostering understanding between Spanish- and English-speaking persons.

Key Words: Bilingual glossary, animal names, botany, fishery, forestry, range, soils, wildlife

ACKNOWLEDGEMENTS

This glossary has required considerable time in preparation by some people. Special recognition for the successful completion of this work is given to Penny Medina for her assistance in translating scientific articles, Diane Prince and Josephine Gomez for their part in manuscript preparation and editing, the Mexican scientists for their reviews, and to David Patton for his support.

RECONOCIMIENTO

Este glosario ha requerido bastante tiempo de preparación en parte de varias personas. Reconocimiento especiales por acabamiento dichoso de este trabajo se da a Penny Medina por su asistencia en traducir artículos de ciencia, Diane Prince y Josephine Gomez por su parte en preparación y compilación del manuscrito, los científicos mexicanos por su revistas, y David Patton por su apoyo.

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January 1988

AN ENGLISH-SPANISH GLOSSARY OF TERMINOLOGY USED IN FORESTRY, RANGE, WILDLIFE, FISHERY, SOILS, AND BOTANY

GLOSARIO EN INGLES-ESPANOL DE TERMINOLOGIA USADOS EN FORESTALES, PASTIZALES, FAUNA SILVESTRE, PESQUERIA, SUELOS, Y BOTANICA

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FOREWORD

Recent symposia, such as Wildlife and Range Research Needs in Northern Mexico and Southwestern United States--1981, and Management and Utilization of Arid Land Plants - 1985, sponsored by the National Institute of Forestry Research of the Subsecretariat of Forestry and Wildlife, Secretariat of Agriculture and Water Resources of Mexico and the U.S. Department of Agriculture, Forest Service have made valuable contributions to the exchange of scientific and technical information regarding management of natural resources. These symposia were part of a continuing agreement between respective agencies to enhance professional capabilities through technology transfer activities. A receptive atmosphere of cooperation has resulted from such activities for the mutual benefit of Mexican and American scientists.

Despite individual efforts to understand and communicate the relevance of these symposia, the language barrier often precludes an effective interchange of ideas. In addition, the specialized meanings of scientific jargon are lost when translated into terms with socialogical connotation. Quite often a given term may have different meanings to a forester, soil scientist or wildlife manager. In order for a listener to receive a clear understanding of the problem being discussed, the translator needs to be familiar with the scientific terminology relevant to the specialized topics.

The purpose of this glossary is to present to translators, scientists, resource managers, administrators and others the Spanish-English equivalent translations of scientific and management terms commonly used in the disciplines of forestry, range management, wildlife management, fisheries, soils and botany. Terms were selected on the basis of common usage and difficulty of translation from various scientific and technical articles which appeared in professional journals, such as Journal of Wildlife Management, Forest Science, Soil Science, Journal of Range Management, Ecology, Ciencia Forestal, and others. Scientific terms are introduced into common usage every time new concepts are formulated, and as such an update of new terminology is needed periodically. While no attempt is made to cover the entire scope of scientific terminology of the respective disciplines, it is anticipated that this glossary will be useful in improving communications and foster understanding between Spanish- and English-speaking persons as well as to serve as a starting point for developing a common understanding of technical terms.

The glossary is composed of two sections. Section one contains the English to Spanish translations, and section two the Spanish to English. Each section is divided into seven subsections, each of which is devoted to terms used within a particular discipline. The text is arranged alphabetically within sections beginning with the English or Spanish keyword, followed by the equivalent translation.

It is understood that some persons may disagree with some terms due to their usage of other similar jargon, but at least they will be aware of its use in other regions and disciplines.

PROLOGO

Reciente simposios (Reunión Sobre La Fauna y Su Medio Ambiente, Noroeste de México y Suroeste Estados Unidos de América 1981; Reunión Sobre Manejo y Utilización de las Plantas de Zonas Áridas 1985) auspiciado por la Subsecretaría Forestal y de la Fauna, y el Instituto Nacional de Investigaciones Forestales de México, y el Departamento de Agricultura, Servicio Forestal de los Estados Unidos han hecho unas contribuciones valiosos al intercambio de información científica y técnica sobre el manejo de recursos naturales. Estos simposios fueron parte de un acuerdo que continua entre las respectivas agencias para aumentar las capacidades profesionales mediante actividades de transferencia de tecnología. Un ambiente muy receptivo de cooperación ha resultado de tales actividades para el beneficio mutuo de científicos mexicanos y americanos.

Aparte de esfuerzos individuales para entender y comunicar la pertinencia de estos simposios, la barrera del lenguaje frecuentemente impide un intercambio efectivo de ideas. Además, los sentidos especializados de la jerga científica se pierden cuando son traducidos a términos con connotaciónes sociológicos. Muy seguido, un término puede tener diferente sentidos para el silvicultor, el científico de suelos, o el manejador de fauna silvestre. En orden para que un escuchante pueda recibir un claro entendimiento del problema que se discute, el traductor tiene que estar familiarizado con la terminología científica pertinente a los asuntos especializados.

El proposito de este glosario es de presentar a traductores, científicos, manejadores de recursos, administradores y otros interesados, las traducciones equivalente en español-inglés de términos comúnes, científicos y de manejo, que se usan en las disciplinas de forestales, manejo de pastizales, manejo de fauna silvestre, pesquería, suelos y botanica. Los términos fueron seleccionados en base al uso común y dificultad de traducción, de varios artículos científicos y técnicos que aparecieron en revistas profesionales, como Revista de Manejo de Fauna Silvestre, Ciencia Forestal (Mexicana y Americana), Ciencia de Suelos, Revista de Manejo de Pastizales, Ecología y otros. Términos científicos son introducidos al uso común cada vez que conceptos nuevos son formulados, por lo que se requiere poner al día los términos nuevos periódicamente. Cuando ningún intento se hace de cubrir totalmente la esfera de terminología científica de las respectivas disciplinas, es anticipado que este glosario sea útil para aumentar las comunicaciones y animar entendimientos entre personas de lengua español y inglés y tambien servir como un punto de partida para el desarrollo de un entendimiento de términos técnicos.

El glosario contiene dos secciones. La primera sección contiene las traducciones de inglés al español, y la segunda sección de español al inglés. Cada sección es dividida entre siete subsecciones, cada cual se dedica a términos que se usan dentro la disciplina particular. El texto esta arreglado alfabéticamente entre las secciones, comenzando con la palabra clave en inglés o español, y seguida por la traducción equivalente.

Se entiende que algunas personas pudieran no estar de acuerdo con algunos términos debido a su propia utilización de jerga similar, pero al menos estarán concientes de su utilización en otras regiones y disciplinas.

CONTENTS

AN ENGLISH-SPANISH GLOSSARY OF TERMINOLOGY USED IN FORESTRY, RANGE, WILDLIFE, FISHERY, SOILS, AND BOTANY

GLOSARIO EN INGLES-ESPANOL DE TERMINOLOGIA USADOS EN FORESTALES, PASTIZALES, FAUNA SILVESTRE, PESQUERIA, SUELOS, Y BOTANICA

Alvin Leroy Medina

ENGLISH-SPANISH

Animals

English	Spanish
alpaca	alpaca
anteater, great	oso hormiguero
anteater, little	oso colmenero
antelope	antílope
antelope	berrendo
badger	tasugo, tejón
bat, fruit	murciélago, bermejizo, za
bear	oso, a
bear, black	oso negro
bear, brown	oso pardo
bear, cub	osezno
bear, grizzly	oso gris
bear, polar	oso polar
beaver	castor
bison	bisonte, cíbolo
bison, female	cíbola
boar, female	jabalina
boar, wild	jabalí
bobcat	gato montés
buffalo	búfalo, la
camel	camello
cat, wild	tigrillo, gato montés
chimpanzee	chimpancé
chipmunk	ardilla listada
coati	coatí
coyote	coyote
deer	venado
deer, blacktail	venado cola negra
deer, fallow	dama
deer, fallow	paleto
deer, fallow female	gama
deer, fallow male	gamo
deer, mule	venado <u>hemionus</u>
deer, whitetail	vanado cola blanca
elephant	elefante, ta
elk	alce, venado alazan
fox	raposa, o, zorra, ro
fox, arctic	zorro, ártico
fox, flying	zorro volador
fox, kit, prairie fox	zorro de las praderas
fox, red	zorro rojo
gazelle	gacela
gazelle, male	gacel
giraffe	jirafa
gnu	ñu
goat, mountain	bicerra
goat, wild	hirco, cabro
gopher	taltuza
hare, jackrabbit	liebre
hyena	hiena
ibex	íbice
jaguar	jaguar

kangaroo	canguro
koala	oso marsupial, koala
lagomorph	lagomorfo
leopard	leopardo
leporid	lepóride
lion	león
lion cub	leoncico, leoncillo, leoncito
lion, mountain	león de montaña
lioness	leona
llama	llama
lynx	lince
marmot	marmota
mole	topo
mouse	ratón, na
mouse, field	campanol
mouse, field	ratón de campo
muskrat	almizclera
muskrat	rata amizclada
ocelot	ocelote, chibiguazu
opossum	churcha, tlacuache, rabopelado, zarigüeya
oryx	orix
otter	ahuizote, lutria, nutria
otter (Lutra hnidobria)	guillín
panther	pantera
peccary	báquira, pécari
peccary, collared	chacharita, jabalina
pig, swine	puerco, cochino, marrano
piscivorous, fish-eating	piscívoro, ra
pond, frog	ranero
porcupine	puerco espin
rabbit	conejo
racoon	mapache
rat, female	rata
rat, kangaroo	rata canguro
rat, water	satirio
reindeer	rangífero, rengífero, reno
rodent	roedor
sheep, mountain	borrego cimarrón
skunk	mapurite, zorrillo, zorrio
sloth	unau, perezoso
sow	cochina
squirrel	ardilla
squirrel, common gray	petigrís
squirrel, flying (Pteromys petaurista)	guigui, ardilla voladora
squirrel, gray	ardilla gris
squirrel, ground	ardilla de la tierra
tapir	tapir
tapir, Mexican	anteburro
tiger	tigre
tigress	tigresa
vicuna	vicuña
warthog	jabalí verrugoso
weasel	comadreja
weasel	mustela
wolf	lobo
wolf cub	lobezno
Woodpecker	picamadero, pájaro carpintero
zebra	cebra

Fishery

algae, green	alga verde
aqueous	acuoso
backwater	remanso
bank/shore	ribera
barbel	barbilla
bass	lobina
belly, fish	ventrecha
benthos	bentos
brackish/briny	salobre
branchia	branquia
brook/creek	rivera
brooklet	arroyuelo
carp	carpa
catch, in a net	redar, red

caudal fin or tail	caudal, cola
crab	cangrejo
cray fish	ástaco
cray fish	cámbaro
crustaceous	crustáceo, a
culture, fish	piscicultura
dam, as with beavers	represa, rebalsar, estanca
dorsal	dorsal
dorsal fin	aleta dorsal
downstream	río abajo
estuary, inlet	estuario, desembocadura
fish	pez
fish, game	pescados de caza
fish, lake	charal
fish, small bait	jaramugo
fish, to	pescar
fisherman	pescador
fishhook	anzuelo, hamo
fishing, angling	pesca
frog	rana
frog, leopard	rana, leopardo
frog, pond	ranero
ground, fishing/ fishery	pesquería
hatchery, fish	piscifactoría
ichthyology	ictiología
lagoon, small lake	laguna
lake	lago
layer, under a river bed	subálveo, a
limit, size	límite de tamaño
line, fishing	sedal
net, dip/scoop net	salabardo
net, fish dip	nansa
net, fishing/seine	tirona
net, netting	red
net, large fishing	cedazo
net, river fishing	redaya
net, shad	almatroque
net, shad	sábalo
nymph	ninfa
opercular	opercular
operculum	opérculo
phytoplankton	fitoplancton
plankton	plancton
rapids, river	rabión, rápidos
rapids, river	recial
reach, stream	tramo fluvial
river	río
rivulet, stream, rill	riacho, riachuelo
roe, fish eggs	hueva
salamander	salamandra
salmon	salmón
seine, fishing net	cercote
shad	sábalo
shad	alosa
spawn, to	desovar
spawning of fishes	freza
spawning season, spawning	desove
stream, torrent rapid	raudal
streambed	fondo del lecho
tadpole	renacuajo
thermic, thermal	térmico, ca
toad	sapo
trade, fishing	pesquería, pesca
trap, fish	butrino
trap, fish/snare	garlito
trout	trucha
underwater, subaquatic	subacuático, ca
upstream	aguas arriba
ventral	ventral

Botany

achene	aquenio
acorn	bellota
agrostology	agrostología
alder	aliso (Alnus)
algae, green	alga verde
ament	amento
androecium	androceo
anther	antera
anthesis	antesis

appressed	comprimido
arborescent	arborescente
arborescent	dendroideo, a
arboretum	arboreto
ash (Fraxinus)	fresno
aspen	álamo temblón
aster	amelo
awned	aristoso, sa, aristado
axil	axila
bearing abundant fruit every year	cadanego, ga
berry	baya
biennial	bianual
biferous	bífero, ra
bifid	bífido, da
billous	velloso, sa
biparous	bíparo, ra
biont	bionte
biota	biota
bipetalous	bipétalo
bipinnate	bipinado, da
birch	abedul
bloom	florecer
borne upon the stem	caulífero, ra
botanical	botánico, ca
botany	botánica
botany	fitología
bract	bráctea
bracteate	bracteado, da
bractlet	bracteola
bryophyte	briófita
buckthorn	aladierno (Rhamnus)
bud	yema
bud (adventitious)	yema adventicia
bud, shoot	gromo
bud (terminal)	yema terminal
bulb	bulbo
bulbous	bulboso, sa
bunch/cluster of roots or flowers	macolla
cactus	cacto, cactus
calyx	cáliz
cambium	cámbium
cane, reed	caña
carpel	carpelo
cattail, bulrush	anea
cattail reed	bohordo
caulescent	caulescente
cedar	cedro
cedar patch (small)	tarajal
cell	célula
cell lumen	cavidad celular
cell plate	placa celular
cherry	cerezo
chlorophyll	clorofila
chlorosis	caquexia or clorosis
clover, trefoil	trébol
cluster, umbel	ramillete, umbela
clustered	arracimado, da
cluster of shoots	amacollar
coleoptile	coleóptilo
columbine	aguileña
coniferous, conifer	conífero, ra
cortex	corteza
creeper	estolonífera
cymose	cimoso, sa
cypress	ciprés
dehiscent	dehiscent
dendrochronology	dendrocronología
dermal	dermico
dicotyledon	dicotiledón
dioecious	dioico
dipetalous	dipétalo, la
disepalous	disépalo, la
Douglas-fir	abeto de Douglas
drupe, stone fruit	drupa
elder	sabuco
elder tree, elderberry	saúco
elm	olmo (Ulmus)
elm grove	olmeda
elm grove, poplar grove	negrillera
embedded	empotrado
endodermis	endodermis
ephedra (joint fir)	belcho, efedra

epigynous	epigino
epiphyte	epifito, a
ethology	etología
evergreen	perennifolia, siempre verde
extruded	expulsado
fasciation	fasciación
feather	pluma
female	hembra
fern	helecho
fibrous	fibroso
fir	abeto (Abies)
fir (Abies)	pinabete
flora	flora
florescence	florescencia
floret	flósculo
flower	flor
flower stalk	rabo, tallo floral
foliose	foliado
follicle	folículo
for leaves to turn yellow	alimonarse, amarillar
formation	formación
foxtail	almorejo
frond, leaf	fronda
fruit	fruta
fungal	fungal, fungoso
fungus	fungo
geniculate	geniculado, da
germination	germinación
globule	glóbulo
grama grass	navajitas
gramineous	gramíneo, nea
graniferous	granífero, ra
gravel bar	depósito de grava
guard cell	célula oclusiva
gymnosperm	gimnospermo, ma
having fleshy leaves	pencudo, da
herbarium	herbario
heterophyllous	heterófilo, la
hydrophilous	hidrófilo, la
hydrophytic	hidrófito, ta
hypogyny	hipoginia

imbricate	imbricado, da
indehiscence	indehiscencia
inferior, lower	infero, ra
inflorescence	inflorescencia
internode	entrenudo
involucre	involucro
involute	involuta
juncaceous	juncáceo
juniper	junípero, enebro
juniper berry	nebrina, enebrina
juniper grove	nebral, nebreda
juniper resin	grasilla, resina
juniper tree or shrub	nebro
knotweed (Polygonum aviculave)	altamandria
lanceolate	arrejonado, da
lanceolate	lanceolado, da
latifoliate	latifolio, a
leaf, petal	pétalo
leaflet	hojuela
leafy	frondoso, sa
legume	legumbre, cambute
lemma	lema
lichen	liquen
ligule	lígula
lobed	lobulado
locust	robinia (Robinia)
maple	arce, maple
maple tree	sácere
membrane	membrana
mesocarp	mesocarpio
mesophyll	mesofilo
mesophyte	mesófito
microphyte	micrófito
mistletoe	muérdago
monocotyledon	monocotiledon
monoecious	monoico
moss	musco, musgo
multifid	multífido, da
multiflora	multiflor
mushroom	champiñon, nanacate, seta
mushroom, toad stool	hongo

mycelium	micelio
mycology	micología
nerve, vein	nervio, vena
nodule	nódulo
nopal, prickly pear	nopal
notched, indented	recortado, da
nut, of any tree	nuez
oak	encino
oak	roble
oak grove or forest	robleda
oat, wild	ballueca, avena silvestre
obovate	obovado, da
onion, wild	ceborrincha
panicle	panícula
paniculate	paniculado, da
pecan tree, pecan nut	nogal
pedicel	pedicelo
pedicellate	pedicelado, da
pedicle	pedículo
peduncle	pedúnculo
perianth	periantio
petal	pétalo
petiole	pecíolo
phanerophyte	fanerófita
phenology	fenología
phycology	ficología
physiognomy	fisonomía
phyton	fitón
phytoplankton	fitoplancton
pine, pine tree	pino
pine cone, pine nut	piña
pine grove or forest	pineda, pinar
pine needle	pinocha
pine needles	alhumajo
pinnate	pinado, da
pinnatifid	pinatífido, da
pinon nut	piñon
pistil	pistilo
pistillate	pistilado, da
plant	planta
plant sap	savia
plants (collectively)	plantas, plantaje
plasmodesmata	plasmodesmos
pod	vaina
pointed	puntiagudo, aleznado, da
pollen	polen
poplar	álamo
prickly pear fruit	tuna
prickly pear growth or thicket	nopalera, tunal
primary wall	membrana primaria
pteridophyte	pteridófito
pubescent, hairy	pubescente
raceme	racimo
rachis	raquis
radiate	radiado, da
radicle	radícula
relic	reliquia
reticulate	reticulado, da
rhizome	rizoma
root	raíz
rootcap	cofia
roots, matted	raigambre
salicaceous	salicáceo
salt cedar	taraje, tamarix
saxicolous, growing among rocks	saxícolo
seed	semilla
semifloret	semiflósculo
sepal	sépalo
septum	septo
sessile	sésil
shoot, scion	vástago, vástiga
shoot, sprout, sucker	retoño
shoots, having many	multicaule
shrub	arbusto
spike	espiga
spikelet	espiguilla
spore	espora
sprig, twig	ramilla
stalk, having only one	unicaule
stalk, stem	cabillo
staminate	estaminado, da

stipule	estípula
substomatal chamber	camara subestomática
sunflower	girasol
sycamore	sicómoro
sympetalous	simpétalo, la
tamarix	tamarisco, tamariz
taproot	raíz pivotante
taxaceous	taxaceo, a
tendril	zarcillo
terminal shoot	guía terminal
tetrandrous	tetrandro, a
tetrapetalous	tetrapétalo, la
thallophyte	talofita
thallus	talo
thorn, caltrop, thistle	abrojo
thorn, spine on plants	pincho, espina
timothy	fleo
to blossom, flower	florecer
tomentose	tomentoso, sa
tree	árbol
trembling poplar, aspen	temblón
trifid	trífido, da
trifoliate	trifoliado, da
tuber, tubercle	tubérculo
tuberose, tuberous	tuberosa, sa
umbel	umbela
uniparous	uníparo, ra
vegetation	vegetación
vein	vena
vernation	vernación
verticil	verticilo
verticil or whorl of leaves	calicillo
vesicule	vesícula
vine	viña
vine tendril	pleguete
walnut	nocedal
walnut grove	noceda, nogueral
walnut tree, walnut wood	nocedal
weeping willow	sauce llorón
white fir	abeto blanco
wild grapevine	parrón
wild plants	rusticano, na, plantas silvestres
willow	salguera, ro, sauce
willow grove	sauceda, salceda, do
willow (<u>Salix</u> <u>incana</u>)	sacina
xerophilous	xerofilo, la
xerophytic, xerophyte	xerófito, ta
xylem	xilema
yarrow (<u>Achillea millefolium</u>)	altarreina

Forestry

acidity	acidez
acreage	superfice medida en acres
acrogenous	producido en el ápice
aerial photo	la fotografía aérea
afforestation	forestación
age	edad
age class	clase de edad
agronomy	agronomía
air dry	secado al aire
allowable cut	posibilidad de corte
amount	importe, cantidad
annual cut	corte anual
annual ring	zona anual de crecimiento, anillo
annual yield	rendimiento anual
aphid	áfido
appraisal	tasación
arboretum	arboreto
area	superficie, área
area regulation	ordenación por área
artificial seeding	siembra
ashes	cenizas
autumn	otoño
average tree	árbol promedio
axe	hacha
backfire	contrafuego

bag	bolsa
ball planting	plantar con terrón
bandsaw	sierra cinta
bark	corteza
bark peeling	descortezamiento
barkbeetle	escolítido, descortezador
basal area	área basal
base map	plano general
beam	viga
bed, nursery	platabanda, vivero
beetle	escarabajo
Biltmore stick	regla de Biltmore
blaze (on a tree)	marcar
blight	tizón
block (cutting)	tramo
blowdown	vuelco por los vientos
bluestain	azulado de madera
board	tabla
boardfoot	pie-tabla
bog peat	turba
bole	rollizo
borer	barrenador
borer, increment	taladro
boundary	límite
broadcast burn	roza a fuego
broadcast seeding	sembrar a voleo
broad-leaved	frondosa
brush-cutter	desbrozadora
buck (in felling)	tronzar
budget	presupuesto
burl	verruga
burn	quemar
by-product	producto secundario
cable	cable
caliper	forcicula
callus	tejido cicatrizal
cambium	cámbium
camp	campamento
canker	cancrosis
canopy	dosel
caterpillar	oruga
caterpillar tractor	tractor oruga
cell	célula
cellulose	celulosa
center rot	pudrición del corazón
chain	cadena
chainsaw	sierra tronzadora de cadena, motosierra
charcoal	carbon
charcoal kiln	carbonera
chip	viruta
chipboard	tablero de particulas
chipper	astilladora
chisel	cincel
chlorophyll	clorofila
chlorosis	clorosis
Christmas tree	árbol de navidad
chromosome	cromosoma
circular saw	sierra circular
cleaning (silv.)	limpia
clearcut	matarrasa, talarasa
clearcut patches	matarrasa por grupos
clearcut strips	matarrasa en fajas alternadas
climate	clima
clod	grumo
clone	clon
codominant	codominante
compass	brújula
computer	computadora
cone (pine)	cono, piña
coniferous	conífera
contour line	curva de nivel
control (pests)	combate
control measure	método de combate
coppice	monte bajo
cord	cuerda
cordwood	leña
corolla	corola
(Cronartium)	roya vesicular
crosscut saw	trozador
cross-pollinate	alogamia
crown (of tree)	copa
crown-class	clasificación arborea
crown-closure	espesura del dosel
crown-fire	incendio de copas

cruise-line	caminato de muestreo
cull (material)	material defectuosa
cultural practice	práctica cultural
cut (to fell)	cortar, talar
cutting	estaquillado
cutting cycle	ciclo de cortas
cutting period	período de cortas
damage	daño
damping-off	enfermedad de las almácigas
data	datos
d.b.h.	diámetro al altura del pecho
debarker	descortezadora
defective	defectuosa
defoliate	deshojar
deforest	desmontar
dendrometer	dendrómetro
density	densidad
development	desarollo
diameter	diámetro
diameter class	clase diamétrica
diameter tape	cinta diamétrica
dike	dique
disease	enfermedad
disk plow	arado de discos
district	distrito
district ranger	ingeniero jefe del distrito
dominant	dominante
dormancy	período de reposo
dormant (seed)	germinación retardada
Douglas-fir	abeto de Douglas
drill (seed)	siembra en hileras
dry-kiln	secadero
dry rot	podredumbre
duff	mantillo
dwarf-mistletoe	muérdago
ecology	ecología
economics	economía
effect	efecto
environment	ambiente
environmental	ambiental
eradicate	erradicar
error (sampling)	error de muestreo
estimation	estimación
even-aged	coetaneo
evergreen	siempre verde
exotic (species)	especie exótica
exploit	aprovechar, explotar
fall (season)	otoño
farm woodlot	monte campesino
fell	talar, cortar, apear
fence	cerco
fence (to)	cercar
fern	helecho
fertilizer (chemical)	abono químico, fertilizante
fiber	fibra
field	campo
field party	cuadrilla de campo
field work	trabajo de campo
financing	financiamiento
fire	fuego
fire control	control de incendios
fire (forest)	incendio forestal
firebreak	franja cortafuega
fireline	cortafuego
flood (to)	inundar
forest	bosque, monte
forest inventory	estadística forestal
forest guard	guarda forestal
forest land	terreno forestal
forest management	manejo forestal
forest policy	política forestal
forest regulation	ordenación forestal
forest research	investigación forestal
forest soil	suelo forestal
forestry	dasonomía
form factor	coeficiente morfico
formula	fórmula
frequency	frequencia
frost	helada
fungal disease	micosis
fungus (growth)	hongo
furniture	muebles

furrow	surco
gall	agalla
gall-midge, nutgall	cecidia
generation	generación
genotype	genotipo
germination	germinación
girdle (to)	anillar
grade (to)	clasificar
graft (to)	injertar
grain (of wood)	grano de madera
ground fire	incendio superficial
grow (to cultivate)	cultivar
growing stock	madera en pie
growth	crecimiento
gully	carcava
hail	granizo
hair roots	raices cepilares
hand (work by)	a mano
hardwood	madera dura (de especie frondosas)
harrow	rastra
harrow (to)	rastrear
harvest	cosechar
heartshake	hendido en el duramen
heartwood	duramen
height	altura
herbicide	herbicida
hereditary	hereditario
horticulture	horticultura
humus	mantillo ácido, humus
hybrid	híbrido
hydrology	hidrología
hypsometer	hipsometro
improvement (forest)	mejoramiento
increment	incremento
increment borer	taladro
increment (mean annual)	incremento medio anual
infest	infestar
infestation	infestación
injury	herida
insect	insecto
insolation	aislamiento

interest (rate)	tasa de interés
intermediate cut	aclareo
interval	intervalo
intolerant	intolerante
inventory	inventario, estadística, censo
irrigate (to water)	regar
knot	nudo
knotty	nudoso
land use	aprovechamiento de tierras
landscape	paisaje
larva	larva
leader (growth)	guía terminal
length	longitud
level (ground)	terreno llano
level (instrument)	nivel
lift (seedlings)	desarraigar
lightning	rayo, relámpago
lignin	lignina
litter (leaves)	hojarasca
litter (refuse)	desecho
load (to)	cargar
loader (jammer)	grua
log	trozo de madera, leño
logging (harvest)	explotación forestal
lookout tower	torre de vigilancia
lop (to)	desramar
lumber	madera aserrada
management objective	objetivo de manejo
management plan	plan de manejo
management unit	unidad de manejo
map	mapa, plano
mark (trees)	señalar árboles
market value	valor corriente
marsh	pantano
mature	maduro
mature stand	maderable
maturity	madurez
meadow	pradera
meadow (wet)	cienaga
mean	promedio, media
mensuration	mensuración
measure	medida

micorrhiza	micorriza
microclimate	microclima
mistletoe	muérdago
moist	húmedo
moisture content	contenido de humedad
mold	moho
morphology	morfología
moss	musgo
moth	polilla
mulch	colchón de materia orgánica
multiple use	aprovecho multiple
natural resource	recurso natural
nursery	vivero
nurseryman	arboricultor
nut	nuez
open space (in forest)	calvero
ornamental (tree)	árbol ornamental
overmature	sobremaduro
overstory	estrato superior
overtopped	suprimido
palea	palea, glumilla
palisade cells	células en empalizada
parasite	parásito
parasitic	parasitario
parenchyma	parénquima
park-like forest	bosque parque
particle-board	tablero de partículas
peel (to)	descortezar
peeler (log)	madera de desenrollo
percent	por ciento
percentage	porcentaje
pest	plaga
pesticide	pesticida
phloem	floema
physiologic	fisiológica
pile	apilamiento
pine (Pinus)	pino
pinecone	cono, piña
pine needle	aguja
pith	medula
planning	planeamiento

plant	planta
plant (to)	plantar, sembrar
plantation	plantación
planting bar	barra de hendir
planting machine	plantadora
planting stock	plantones
plot	parcela
plow (to)	arar
plywood	triplex
poison (to)	envenenar
pole	poste
pollinate	polinizar
pollution (air)	polución del ambiente
pollution (water)	polución del agua
preparatory cutting	corta preparatoria
prism	prisma
provenance	origen, procedencia
prune (to)	podar
pulpwood	madera en rollo
railroad tie	durmiente de ferrocarril
random	azar
rate of interest	tasa de interés
recreation	recreo
reforestation	reforestación
regeneration	regeneración
regeneration cut	corta de regeneración
regulation of cut	ordenación del aprovechamiento
relascope	relascopio
research	investigación
resin	resina
resources	recursos
ring, annual	anillo anual
ringshake	acebolladura
road, access	camino acceso
road system	red de caminos
rot	podredumbre
rotation	rotación
roundwood	madera en rollo
row	fila, hilera
rust (disease)	roya
safety	seguridad
salvage (cutting)	corta de salvamiento

sample	muestra
sample distribution	distribución de muestra
sample plot	parcela de prueba
sample tree	árbol tipo
sampling	muestreo
sampling error	error de muestreo
sandy	arenoso
sap	savia
saplings (thicket)	monte bravo
sapwood	albura
savanna	sabana
saw (to)	aserrar
saw	sierra
sawdust	aserrín, serraduras
sawmill	aserreradero
sawtimber	madera para aserrar
scale (of map)	escala
scale (timber)	medición de volumen
scenic beauty	belleza del paisaje
scion	pua para injertar
scrub (growth)	matorral
season (of year)	estación
seed	semilla
seedbed	cama de siembra almaciga
seeding	siembra
seedling	brinzal, semillón, plantula
seedling stage	repoblado
seed tree	árbol semillero
seed tree cutting	corta diseminatoria
seed tree method	talarasa con portagranos
selection forest	bosque de entresaca
selection thinning	aclareo selectiva
selective cut	corta de entresaca
shade	sombra
shade tolerant	umbrofila
shake (heartshake)	tejamanil
sharpen	afilar
shelterwood (system)	cortes sucesivas
silvicultural	silvicultural
silvicultural system	sistema silvicultural
silviculture	silvicultura
site quality	calidad del sitio

skid (logs)	arrastrar (extraer)
skidding	extraccíon
slab	costero
slash	desechos de la corta
slope	questa, pendiente
snag	fuste muerto
softwood	madera blanda (de conífera)
species	especie
spiral (grain)	torcida
split (to)	rajar
spray (to)	rociar
spring (season)	primavera
stand improvement	tratamienta cultural
stand (of trees)	masa, macizo
standard deviation	deviación estandar
standing timber	madera en pie
stem (bole)	tronco, elfuste
stereoscope	estereoscopio
stigma	estigma
stocking	densidad
stratification	estratificación
stratified sample	muestreo estratificado
strip	faja, banda
stump	cepa, tocón
stumpage (value)	valor de madera en pie
summer	verano
suppressed	suprimido
sustained yield	rendimiento sostenido
system	sistema
table (of figures)	tabla, cuadro
tape (measuring)	cinta de medición
temperature	temperatura
termite	termita, comejen
thin (to)	aclarear, entresacar
thinning from above	aclara por lo alto
thinning from below	aclara de la parte inferior
thinning method	método de aclareo
timber	madera
tongs	tenazas
top	ápice
top (to)	despuntar

top diameter	diámetro superior
tractor	tractor
trail (path)	vereda
transplant	trasplantar
tree	árbol
tree (relating to)	arborea
turpentine	trementina
undercut	incisión de corta
uneven-aged	disetáneo
unit (management)	unidad de manejo
unit (of area)	unidad de área
unit (organization)	unidad del organización
utilization	aprovechamiento, utilización
vegetation	vegetación
veneer	chapa de madera
vigor	vigor
vine	viña
volume	volumen
volume (of a stand)	masa
volume regulation	ordenación por volumen
volume table	tabla de volumen
waste	desperdicio
watershed area	cuenca
watershed (boundary)	divisoria de aguas
weather	tiempo
wedge	cuña
weeding	deshierbe
weeds	malezas
weight	peso
whorl (of branches)	verticilo
windthrow	vuelco por los vientos
winter	invierno
wither	marchitar
wood	madera
woody plant	planta leñosa
xylem	xilema
yield	rendimiento
yield table	tabla de rendimiento

Soil

abutment	estribo
accretion	embancamiento, aluvionamiento
acid	ácido
acidity	acidez
aggradation	aterramiento
aggregate, soil	agregado
alkali	álcali, caliche
alkaline	alcalino
alluvial	aluvial, aluvional
alluvial fan	cono de deyección abanico aluvial
alluvium	aluvión
analysis, mechanical	análisis mecánico
anthropic	antrópico
apedal	apedal
aquic	acuico
argillic, clay	arcila, arcilla
argillic, clayey	arciloso, arcilloso
auger, soil	sonda de tierra
autoclave	autoclave
azonal, soil classification	azonal
backfill, fill	terraplén
badland, clay loam	terreno abarrancado
badlands	tierras de baldío
bedload	cargasolida
bedrock	lecho de roca
boulder, rock	pedrejón, peña, roca
breccia	brecha
calcareous	calcáreo
calcic	cálcico
cambic	cámbico
catena	catena
clay loam	greda, franco arcilloso
clay, loamy	gredal
clay mud, silt	barro
clay pan	tosca arcillosa
clayey	barroso, sa
cleavage	carga de raja
clod	terrón
cobble	guijarro
cobbly land	guijarral
colloid, soil	coloide del suelo

colluvium	colluvión
concretion	concreción
consistence, soil	consistencia del suelo
crust	costra
desert pavement	adoguina
desert varnish	barniz del desierto
dirt, soil	tierra
drainage basin	cuenca hidrográfica
durinode	durnudo
duripan	dubstrato, duro
edaphic	edáfico, ca
eluviation	eluviación
eolian	eólico
erode	desgastar, erosionar
erosion	erosión
erosion, accelerated	erosión acelerada
erosion bank	desprendimiento de ribero
erosion, gully	erosión de carcavas
erosion, pavement	pedrera de erosión
erosion, rill	erosión por regueros
erosion, sheet	erosión laminar
erosion, splash	erosión superficial
floculation	floculación
friable	friable
granular	granuloso
gravel bar	depósito de grava
gravel, coarse sand	grava
gravelly, stony	guijoso, sa
hardpan	capa dura, tosca
histic	histico
illuvial	iluvial
illuviation	iluviación
impermeable layer	capa impermeable
landform	forma terrestre
landslide	derrumbe
leaching	lixiviación
liming, soil	encalado
lithic	lítico
lithosequence	litosecuencia
loam	arcilla
loamy sand	arena francosa, franca
loess	loess
mesic	mesico

microrelief	microrelieve
mollic	molico
ochric	ocrico
overburden	sobrecarga de suelo
oxic	oxico
paralithic	paralítico
peak, high hill	cabezo
peat	turba
pebbles, stones	rocalia
ped, earth clod	terrón
pediment	frontón pendiente
pedology	pedología
pedologist	pedólogo
pedon	pedón
peneplain	peniplanicie
percolate	percolarse
pergelic	pergelico
phase	fase
platy	en placas
podzol	podzol
regolith	regolita
rill	riachuelo
runoff	escorrentía, escurrimento
salic	salico
sampler	sacamuestras
sampling	muestreo
sand	arena
sand dune	medano, duna
sandy clay	arcillo arenoso
sandy clay loam	franco arcillo arenosa
sandy ground or place	arenal
sandy, heavy coarse	sábulo
sandy loam	franco arenoso
silt	limo
silt loam	franco limoso
siltation	aterramiento
silty clay loam	franco arcillo limoso
soil, acid	suelo ácido
soil, aeolian	suelo eólico
soil, alkaline	suelo alcalino
soil, a loam	tierra franca
soil, calcareous	suelo calizo
soil, chestnut	suelo castaños

soil, clay loam	suelo franco arcilloso
soil, colluvial	suelo coluvial
soil creep	dezlizamiento de suelo
soil, degraded	dezlizamiento deslavado
soil depth	dezlizamiento, profundidad del suelo
soil, earth	suelo
soil, eluvial	dezlizamiento eluvial
soil horizon	horizonte edáfico
soil, immature	suelo inmaturo
soil, loam	tierra franco
soil mantle	manto de suelo
soil, mature	suelo maduro
soil, mineral	suelo mineral
soil, moisture	suelo, humedad del
soil, muck	suelo humifero
soil, normal	suelo clímax
soil, organic	suelo orgánico
soil, pit	pozo agrológico
soil porosity	porosidad edáfica
soil profile	perfil del suelo
soil, residual, primary	suelo sedentario
soil, saline	suelo salino
soil series	suelo, series de
soil, skeletal	suelo esquelético
soil texture	suelo, textura del
soil, top-	capa arable
soil, top	suelo vegetal
soil type	suelo, tipo del
soil, virgin	liego, ga
spodic	espódico
stony	pedregoso, sa
stony ground	pedregal, pedroche
stony, rocky ground	cantalinoso, sa
streambed, riverbed	álveo
subsoil	subsuelo
substratum	substrato
survey, soil	investigación de suelos suelos
topsoil	mantillo
thermic	térmico
udic	údico
ustic	ústico

Wildlife

abiotic	abiótico
abomasum	abomaso
accipiter	accípitre
activity	actividad
aesthetics	estético
amphibian	anfibio
anaerobic	anaeróbico, ca
anatomy	anatomía
animal, big-hoofed	cascudo, da
animal, wild, or beast	fiera
annulus	anillo
antler	asta
antler, budding	mogote
antlers/fawns first growth	cerceta
antlers, to cut off	descogotar
aquatic	acuático
archer, bowman	asaeteador
area, concentration	área superpoblada
area, key	pastizal tipo
area, primitive	reserva primitiva
area, wilderness	zona selvática
arthropod	artrópodo, da
autopsy	autopsia
aviary	pajarera
bag limit	cantidad permitible
bait	cebo, carnada
beard	barba
behavior	comportamiento
bifurcate	bifurcado, da
big-footed	patón
bill	pico
biological	biológico, ca
biologist	biólogo
biometry	biometría
biped	bípedo, da
bird	pájara, ro

bird, game	ave de casa
bird, leader of migratory flock or leading dog in a pack	guión
bird of prey	raleón, ave de presa
birds, insectivorous	aves insectivoras
birds, migratory	aves migratorias
birth, giving annually	cadañero, ra
bleating, sound of deer, sheep, goats	balido
blind, hunter's	aguardadero, aguardo
blind, hunter's/hut	huta, paranza
bovid	bóvido
bovine	bovino, na
breakout of egg shell using bird's beak	apitonar
breast of a fowl	pechuga
brood, nest of eggs	nidada
brood of chicks	echadura de pollos, cría
buck, immature	alero
burrow, badger	tejonera
cackle, to/caw, croak	graznar
call, bird	chifle
call, decoy	chillido
call, deer (bleet)	gamitido
call, deer/to sound (as with deer call)	gamitar
call, to call the doe (as a buck in a rut)	roncar
canid	cánido
canine	canino
capacity, carrying	capacidad de carga cinegética
carnivorous	carnívoro, ra
cat	gata, o
caw, cackle, croak	graznido
census, game	censo de caza
cervidae	cérvidos
claw/talon	garra

climbing, mountain	alpinismo
cloven-hoofed	patihendido, da
cock, rooster	gallo
coefficient, digestion	coeficiente de degestibilidad
cohort	cohorte
cold-blooded	hemacrimo
conserve, to	conservar
control, biological	control biologíca
coo, to (doves)	zurear
cooing, (doves)	zureo
count, strip	medidas en bruto
cover, escape	resguardo natural
cover, game	cobijo
covey, brood	pollada, nidada
covey of birds	bandada
cycle, life	ciclo vital
cyclic	cíclico
cyst	quiste
decoy, lure	añagaza, señuelo
deer	venado
deer, small or young	gamezno
den, bear's/lair	osera
den, lair	guarida
density	densidad
depredation	depredación
desertion	deserción
diet	dieta
digestibility	digestibilidad
digitate	cisípedo, digitado
disembowel	desentrañar
dispersion	dispersión
display of outstretched wing	exployada
distribution	distribución
diversity	diversidad
docile	dócil
dogs, pack of	muta
dormant	letargo
down, bird	plumón
duck	pato
duck, wild	alavanco

duckling	anadeja, anadino	gestation	gestación
dwelling/cave	cavernícola	gray-haired	pelicano, na
dwelling, earth	terrícola	gregarious	gregario, a
eagle	águila	ground, hunting	cazadero
ecology	ecología	habitat	habitación, habitat
ectoparasite	ectoparasito	hair, fur	pelo
edible	comestible	hair, to grow a new coat/ feathers	pelechar
egg	huevo		
elk	anta		
elk, moose	alce	heat, in season (female)	celo
embryo	embrión		
entrails	entrañas	herbivorous, herbivore	herbívoro
equilibrium	equilibrio		
equine	equino	herd, flock	manada
escape/flight	escape, vuelo	heterogeneity	heterogeneidad
eviscerate	extinción	hibernation	hibernación
exotic	exótico	hide, (to) in an inaccessible portion of burrow	encodillarse
extinct	extincto		
falcon, newborn	niego		
falconry/hawking	halconería, cetreria	hiss, hissing	silbo
falcons, eagles, birds of prey	falconidos	hole, burrow	hurera, huronera
		hole, fox/burrow den	raposera
fat, animal	enjundia	hole, fox	zorrera
fauna	fauna	homeothermal	homeotermo, ma
fawn	cervato	hoof, (cloven-hoofed animal)	pesuña, pezuña
feather, to pluck off	desemplumar		
feathery/downy	plumoso, sa	horn, budding of goat, deer	pitón
fecundity	fecundidad		
female	hembra	horn of animals	cuerno
feral	feral	horned, with horns	astado
fertilization	fertilización	horns, shedding of	desmogue
fetal	fetal	horns, to shed	desmogar
fetus	feto	hunt, a	caza
flank of an animal	ijada	hunt/hunting	caceria
fledgling	guácharo, ra/guacharro, ra	hunt (birds)	pajarear
flock	rebaño	hunt, to	cazar
flock of birds	parvada	hunter	cazador, ra
flock of turkeys	pavada	hunter	montero
gallinaceous	gallináceo	hunter, head	cazador de cabezas
game, big	caza mayor	hunter, lying in wait	paradislero
game, small	caza menor	hunting, big game	montería
game, upland	caza menor deportiva	hybrid	híbrido, da
genotype	genotipo	immature	inmaturo, ra

impregnate, to/ inseminate	fecundizar inseminar
inbreeding	endogamia
incubate. to	incubar
incubation	incubación
innate	innato
innate, inherent	connatural
interaction	interacción
interspersion	entremezcladura
inventory	inventario
invertebrate	invertebrado, da
lactation	lactancia
law, game	ley da caza
lay (eggs)	aovar
leporid	lepóride
license	licencia
litter, brood of animals	camada
litter of animals	cachillada
lizard	fardacho
lizard	lagartija
lizard, horned	lagartija cornudo
longevity	longevidad
male	macho
mammalian, mammal	mamífero
mammary	mamario, ria
management, game	reglamentación de caza
marsupial	marsupial
meat, to debone	desencarnar
meat, game	salvajina, no
metabolic	metabólico
migration	migración
migratory (birds)	peregrino, na
mimicry	mimetismo
mobility	movilidad
monogamy	monogamia
mortality	mortalidad
mottled	jabado, da
mutualism	mutualismo
mutualist	mutualista
natal	natal
natality	natalidad
native	nativo, va

natural	natural
nest	nido
nest, brood of eggs or newly hatched birds	nidada
nest, eagle	aguilera
nest, of mice	ratonera
nest, to	anidar
nest, to	nidificar
nesting place/box	nidal
neutralism	neutralismo
neutralist	neutralista
non-poisonous	atóxico
nourishment	alimentación
nutrition	nutrición
omnivorous, omivore	omnívoro, ra
ornithology	ornitología
oviparous	ovíparo
palmate	palmeado
papilla	papila
parasite	parasito, ta
parasitic	parasítico, ca
parasitism	parasitismo
partridge, ptarmigan	perdiz
partridge, young	perdigana, perdigón
path, trail	vereda
paw, foot	pata
paw, of large felines	zarpa
peliage, hair	pelaje
pellets, deer, rabbits, or sheep fecal	cagarruta
periodic	periódico, ca
pesticide	pesticida
phenotype	fenotipo
phenotypic	fenotípico, ca
phylogeny	filogenia
piglet, suckling pig	gorrín
place, breeding	criadero
place, hiding	escondedero
place, nesting/box	nidal
place, rutting or mating	bramadero

place, wallowing of animals	revolcadero
plumage	plumaje
poacher	cazador furtivo
poison, venom	ponzoña
population	población
post, lookout	descubridero
pouch, cheek	abazón
predator	alimaña, predator
pregnant	preñada
prehensile	prensil
preserve, game	coto de caza
pullet	polla
quadruped	cuadrupedo
rabid	rábico
radius	radio
raptors	rapaces
ratio, kill	capacidad de caza
rattlesnake	víbora de cascabel, crótalo
reconnaissance, range	estimación de pastizales
recreation	recreación
recruitment	reclutamiento
refuge	refugio
refuge, game	refugio de caza
remote	remoto, ta
repopulate, to	repoblar
reptile	reptil
resources, natural	recursos naturales
respiration	respiración
restoration	restauración
reticulum of a ruminant	redecilla
rhythm	ritmo
rodent	roedor
rostrum	rostro
routine	rutina
rumen	rumen
rumen (ruminants)	rumen
ruminant	rumiante
rumination	rumia, rumiadura
rut, heat of swine and sheep	verriondez
rut, rutting season	ronca
rutting in swine and sheep	verriondo, da
sac, air/cell	saco aéreo
sac, yolk	saco vitelino
scats, bird of prey/ droppings	tullidura
season, closed	temporada cerrada
season, mating of animal, (rut)	brama
season, open	temporada abierta
secretion	secreción
sheep, female	oveja
shelter, refuge	recepto
shoot (to), birds on the wing/flight	volateo
short-haired	pelicorto, ta
skin, hide	cuero
skin, hide	pellejo
snake, large	culebrón
snake, small	culebra
snare	alzapié
snare, bird	esplique
snare, bird, or animal trap	orzuelo
solitary	solitario
songbird	ave cantora
specialist	especialista
specialist, predator control (warden)	alimañero
species	especie
species, indicator	especie indicator
species of large deer	especie alanés
specimen	espécimen
split-hoofed, like goats	caprípedo, da
stalk, to	amaitinar
stomach	panza
swampy, bog	pantano
swampy, boggy	paludoso, sa/palustre

symbiosis	simbiosis
symbiotic	simbiótico
tail	rabo
tail, animal	cola
tail, having a prehensile	caudimano
telemetry	telemetría
terrestrial	terrestre
territorial	territorial
toe, of cloven-footed animal	carnicol
tooth, canine	colmillo
tooth/tusk/fang	diente
track, animal	huella
track, trail of an animal	pista
trap, snare	trampa
trap, to	atrapar
trapper	cazador de alforja
trapper	trampero, ra
tree, to	encogollarse
trend	tendencia
triangulation	triangulación
turkey	pava, pavo, guajolote
ungulate	ungulado
value, food	alimenticio
vampire	vampiro
venison	carne de venado
venom	veneno
vertebrate	vertebrado
viper	víbora
viviparous	vivíparo
wallow, to	encenagarse
warm-blooded	hematermo
warden, game	guardabosque
wasp	avispa
watcher, bird	observador de pájaros
waterfowl	ave acuática
webfooted	palmípedo
white-tailed	rabicán, no
wild animals	animales salvajes
wild, untamed	salvaje
zone, climatic	zona climática

Range

abundance	abundancia
acre-foot	pie-acre
adaptation	adaptación
agriculture	agricultura
agronomy	agronomía
alpine	alpestre, alpino, na
amplitude	amplitud
analysis	análisis
analysis, qualitative	análisis cualitativo
analysis, quantitative	análisis cuantitativo
analytic, analytical	analítico, ca
arctic	ártico, ca
area, basal	área basal
area, burnt woodland	chamicera
area, that remains green during dry season	fresquedal
arid	árido
aspect	aspecto
ass, donkey	burro
ass, female	burra
asses, herd of donkey	burrada
associes	asocies
atmosphere	atmosfera
autecology	autecología
autogamy	autogamia
barley	cebada
barn, cattle	tenada
barren	estéril
belt	faja, zona
bioclimatology	bioclimatología
biogenic	biógeno, na
biogeography	biogeografía
biomass	biomasa
biome	bioma
biota	biota
biotic potential	potencial biótico
biotype	biotipo

birth, to give	parir
bovine	bovino, vacuno
breed	crianza
brooklet	arroyuelo
browse, forage cut for fodder	ramón
browse, to	ramonear
brush control	control de arbustos
buck, young	novillo
bud, sprout, shoot	brote
bud, to sprout	brotar
budding, sprouting	brotadura
bull	toro
bunchgrass	zacate amacollado
canopy (herbaceous)	cobertura de follaje
capacity, grazing	capacidad de pastoreo pastoreo
carbohydrate	carbohidrato
cattle	ganado
cattle, community herd of	manada
cattle, drove of young	novillada
cattle, in rut	toriondo
cattle, parturition place of	paridera
cattle, parturition time of	parición
cattle, pasture for	vequeril, potrero
cattle ranching or breeding	ganadería
cattle, rut of	toriondez
cattle terraces	terracillas de sobrepastoreo
cattle, to corral	encorralar
cattle, to gather	acubilar
cattle, to gather into a fold	embrosquilar
cattle, to put out to graze	empotrerar
check dam	dique de consolidación
chemical, chemist	químico
chemistry	química
class, age	clase de edad
class, canopy	clase de cobertura de follaje
class, condition	clase de condición del agostadero
class, diameter	clase diamétrica
class, life-form	clase vitamorfológica
class, height	clase de altura
classification	clasificación
classification, range	clasificación de pastizales
clearing	raso
climate	clima
climatic	climático
climax	clímax
closed canopy	cobertura cerrada
coaction	coacción
cohort	cohorte
collection	recolección
community	comunidad
community, climax	comunidad clímax
community, plant association	asociación de plantas
competition	competición
consociation	consoción
consocies	consocies
constancy	constancia
consumer	consumidor, ra
continuum	continuo
corral, pen, sty	encerradero, corral
corral, to pen	arredillar
countryside	campiña
cover, range plant	cobertura del pastizal
cover, vegetation	cobertura vegetal
cover, vegetative	cobertura vegetante
cow	vaca
cowhand	vaquero, ra
cow, herd	vacada, manada
crop, forage	cosecha de foraje
defecate, to	defecar
defoliate, to	defoliar
defoliation	defoliación
dense	denso, sa

dense, woodland or brush thicket	arcabuco
densitometer	densitómetro
density	densidad
density, stand	densidad de masa
desert, wasteland	desierto
dioecious	dioicas
dispersal	dispersión
dominant	dominante
donkey	burro, burra
driveway, stock	paso de ganado
drought, dry season	seca, sequía
dry matter	materia seca
dung, cattle	boñigo
dung, horse, cow	bosta
ecologic, ecological	ecológico
ecologist	ecólogo, ga
ecology	ecología
ecotone	ecotono
ecotype	ecotipo
edaphic	edáfico
enclosure	cercado, cercamiento, área de exclusión
endemic	endémico
environment	ambiente
environmental	ambiental
ephemeral, stream, water course	arroyo
equilibrium	equilibrio
erosion	erosión
erosion streambank	desprendimiento de ribera
eutrophic	eutrófico
ewe	oveja, borrega
ewe, small or young	ovejuela
exposure	exposición
faciation	faciación
facies	facies
factor, proper use	coeficiente de aprovechamiento
farm, grange	granja
farm, owner	finquero
farmer	granjero, ra
farming	granjería
felling or clearing of trees	desmonte
fertile lowland	vega
fidelity	fidelidad
field (the field)	campo
fire	incendio, fuego
fire effects	efectos del fuego
fire, forest	incendio de bosques
fire, range	incendio del pastizal
fistula	fístula
floodplain	lecho de inundación
foliage	follaje
follow	barbecho
forage	forraje
forage, to	forrajear
forage value	valor forrajero
forb, weed	hierba
forest, wood, grove	foresta
forestation	forestación
forester, forest keeper	forestero
forestry, related to forests	forestal
frequency	frecuencia
gage, rain	pluviómetro
garden, botanical	jardín botánico
gauging, water current	hidrometría
goat, female	cabra
goat, male	bode, macho cabrio
goat, young	cabrito, ta
goats	ganado caprino
gradient	gradiente
grass-eating	graminívoro
grasshopper	chapulín
graze, to	pastorear, apacentar
graze, to put out to graze	pacer
grazing, conservative	pastoreo limitado
grazing, deferred	pastoreo diferido
grazing, premature	pastoreo prematuro

grazing right	derecho de pastoreo
grazing, rotation	pastoreo en rotación
grazing, selective	pastoreo selectivo
greenhouse	invernadero
ground cover	covertura del subsuelo
groundwater	capa freática
grow, to grow roots	enraizar
grow, to grow shoots, sprouts	entallecer
grow, to grow among other plants	entrecriarse
growing season	período vegetativo
gulley, gulch, ravine	cañada, barranca
gullies, to form	arroyar
habit, grazing	forma de pastar
habitat	habitat
half-shrub	semiarbusto
halophyte	halófita
halophytic	halófilo
hay	heno
hay, fodder, grass feed	forraje
hedged	recomidas
heifer	vaquilla
hemisphere	hemisferio
herbaceous	herbaceo
herbage	herbaje
herbarium, botanist	herbario
herbicide	herbicida
herbivore, herbivorus	herbívoro
hierarchy	jerarquía
hill	loma
hill, knoll, butte	otero
hillside	ladera
homogenous	homogéneo, a
horizon	horizonte
horse	caballo
horse herd	caballada
horses	ganado caballar
humidity	humedad
humus	humus
hydrology	hidrología

hydrophytic	hidrófito
hydrosere	hidrosere
ignite, set fire	encender
inclination, slope	inclinación de la pendiente
increaser	acrecentado
index	índice
inventory	inventario
investigation,	investigación
irrigation	regadura, irrigación
irrigation ditch	regadero
irrigation, canel	regona
island	isla
isothermal	isotermo, isotérmico
knoll, mound (small)	montículo
land, dry barren	secadal
land, fallow	añojal
land, flat tract of, on mountain slope	sillada
land, pasture	zacatal
land, small tract of	hazuella
land, tract of	terreno, na
land, tract of arable	haza
land, wasteland, barren	yermo
landholder	terrateniente
leaves, dry, falle, brushwood	borusca
lick, salt	salega, lamedero
life-form	forma biológica
lignin	lignina
litter, (leaves, etc)	broza, hojarasca
management, forest	ordenación de montes
management, livestock	ordenación de la ganadería
management, range	ordenación de pastos
management, watershed	manejo de cuencas
management, wildlife	manejo de fauna silvestre
manure	estiercol
marsh	cienaga
marshland, marsh	fachinal
marshland, swamp	almarjal
meadow	pradal, prado

meadow, small	pradejón
mensuration	mensuración, medición
mesophyte	mesófito
method	método
methodology	metodología
microclimate	microclima
monoecious	monoico
mosaic	mosaico
mountain	montaña
mountain pass or small hill	collado
mountainous	montañoso, sa
mouth of river	desembocadura
muddy, boggy	lodoso
mulch, compost	latame
native, indigenous	nativo
natural	natural
nature	naturaleza
niche	nicho
noxious, harmful	nocible, nociva
nutrient	nutriente
nutrition	nutrición
oak grove or wood	carvajal
oligotrophic	oligotrófico
orchard	arboleda
organic matter	materia orgánica
overgrazing	sobre pastoreo
overgrazing	pastoreo excesivo
paddock, grassland	herbazal
park	parque
pasture, (area) for cattle	potrero, pastizal
pasture, fodder	pastura
pasture, grazing area	apacentadero, potrero pastizal
pasture, used in summer	veranadero
pastureland	pastadero
ped, clod of earth	terrón
period, grazing	período de pastoreo
periodic	periódico, ca
phenology	fenología
photosynthesis	fotosíntesis

physiognomy	fisonomía
phytogeography	fitogeografía
phytosociology	fitosociología
plant, indicator	planta indicadora
plant, to	plantar
plant uprooting	rancajada, desenraizar
plasticity	plasticidad
plot, experimental	parcela experimental
plot, study	parcela de ensayo
plot, transect	parcela de muestra
plow, to	barbechar
plowing of	barbechada
pollination	polinización
pollution	polución
polyandrous	poliándro, ra
polygamous	polígamo, ma
polymerous	polímero, ra
pond, ephermeal	bodón, estanque
pond, small shallow	badina
pond, stock tank	albuhera, amanal
pool, pond, reservoir	estanque
population	población
prairie, plain	llano, pradera
presence	presencia
primary succession	sucesión primaria
producer	productor
profile	perfil
prune, to, trim a tree	podar
pull, up by the roots roots	desarraigar, desenraizar
quadrat	cuadrato
radiation	radiación
ranch	rancho
rancher	ranchero
range, or grazing allotment	lote de pastos
range appraisal	valoración del pastizal
range condition	condición del pastizal
range improvement	mejoramiento
range, short mountain	serrijón, serrania
range of small hills	colladía
range, open	pastadero libre

range, rugged mountain	sierra
range, yearlong	pastadero permanente
reconnaissance	reconocimiento
reforestation	reforestación
relationship	relación
relic	reliquia
reservation	reservación
reserve	reserva
reticulum (ruminant)	redecilla
revegetation	revegetación
riparian	riberano, na, ribereño, na
riparian, (terrestria)	amnícola
rock, stone	piedra
Rocky Mountains	Montañas Rocosas
Rocky Mountains	Montañas Rocallosas
rocky, stony	rocalloso, sa
rocky, stony	rocoso, sa
rocky terrain	peñascal
row of trees, plants	linio, hilera
rugged, rough terrain	fragoso, escabroso
ruggedness, wilderness	montuosidad
rumen	rumen
ruminate, to	rumiar
rumination	rumia, rumiadura
saline	salino, na
saline ground	salobre
salinity	salinidad
salt, to feed to livestock	salgar
season, period	temporada
sediment	sedimento
sedimentary	sedimentario, ria
sedimentation	sedimentación
seedbed, plant nursery	plantario, cama de siembra
seed drill	sembradora de hileras
self-fertilization	auto fertilización
self-pollination	auto polinización
semi-arid	semiárido, da
sharecropping	aparcería

sharp peak or summit	picacho
sheep, flock of	carnerada, rebaño
sheep, flock of yearling	borregada
sheep, ram	carnero
shepard	borreguero, pastor
shrub	arbusto
shrub-like	arbustivo, va
sigmoid	sigmoideo, a
singe, to sear, scorch	chamuscar
site	sitio
slope, gradient	cuesta, pendiente
sociability	sociabilidad
sod	césped
sod, grass	hierba de césped
soil, dry barren	secaral
soil, earth	suelo, tierra
soil, hard crust	tastaña
soil, survey	apeo de suelos
species	especie
specimen	espécimen
spring (water)	fuente, manantial
stagnant	estancado
stand of trees	masa
steep rugged rock, crag	peñasco
steep slope, ravine	garma
steepest part of hill or slope	varga
stratum	estrato
streambank	ribera del torrente
streambed	fondo del lecho, álveo
streammouth	desembocadura
subalpine	subalpino, a
subspecies	subespecie
substratum	substrato
subterranean	subterráneo, a
subtropical	subtropical
succession	sucesión
summer	verano
summer season	veranada
summit	cumbre

survey	reconocimiento
systems	sistema
systemmatic	sistemático, ca
technique	técnica
technology	tecnología
terrestrial	terrestre
theory	teoría
thicket	boscaje
tillage	labranza
tolerance	tolerancia
tract, woodland with fall and lofty	oquedal
trample, to	patullar, pisotear
transect	transecto
transpiration	transpiración
tree fork or branch	orqueta
tree, half-burnt, or log	chamizo
tree stump	tocón
trees, bare of	subafluente
undergrowth	
tributary	
trophic	trófico
tundra	tundra
twig	verdasca, ramita
undergrowth, brushy with	brozoso, sa
understory	estrato inferior
ungulate	ungulado
uptake	asimilar
use, utilization	aprovechamiento

vegetation	vegetación
vegetative	vegetativo, va
vigor	vigor
vitality	vitalidad
volunteer plants	plantas espontáneas
watershed	cuenca
wave on water	onda, ola
weeds (noxious)	malezas
weeds, forbs	yerbas
wetting agent	agente humectante
winter blooming	hiemación
wintering place	invernadero
wire, barbed	alambre de puas
wooded, densely	arcabucoso
wooded, densely	boscoso
woodland	arboleda
woodland	monte, bosque
woods, forest	bosque
woods, forest	selva
woods, of the	selvático, ca
xerophyte	xerofita
xerophytic	xerofítico
yearling, bull calf	becerro
yearling, calf or lamb	añojo, ja
yearling, female calf	becerra
yearling, lamb	borrego, ga
zonation	zonificación
zone	zona
zone, buffer	zona amortiguada

Animales

Español	Inglés
ahuizote	otter
alce, venado alazan	elk
almizclera	muskrat
alpaca	alpaca
anteburro	Mexican tapir
antílope	antelope
ardilla	squirrel
ardilla de la tierra	ground squirrel
ardilla gris	gray squirrel
ardilla listada	chipmunk
ardilla voladora	flying squirrel (<u>Pteromys petaurista</u>
báquira	peccary
bermejizo, za	fruit bat
berrendo	antelope
bicerra	mountain goat
bisonte	bison
borrego cimarrón	sheep, mountain
búfalo, la	buffalo
cabro	wild goat
camello	camel
campanol	field mouse
canguro	kangaroo
castor	beaver
cebra	zebra
chacharita	collared peccary
chibiguazu	ocelot
chimpancé	chimpanzee
churcha	opossum
cíbolo, a	bison
coati	coati
cochina	sow
comadreja	weasel
conejo	rabbit
coyote	coyote
dama	fallow deer
elefante, ta	elephant
gacel	male gazelle
gacela	gazelle
gama	female fallow deer
gamo	male fallow deer
gato montés	bobcat, wild cat
guigui	flying squirrel (<u>Pteromys petaurista</u>)
guillín	otter (<u>Lutra</u> <u>hnidobria</u>)
hiena	hyena
hirco	wild goat
íbice	ibex
jabalí	wild boar
jabalí verrugoso	warthog
jabalina	female boar, collared peccary
jaguar	jaguar
jirafa	giraffe
koala	koala
lagomorfo	lagomorph
león	lion
león de montaña	mountain lion
leona	lioness
leoncico, leoncillo, leoncito	lion cub
leopardo	leopard
lepóride	leporid
liebre	hare, jackrabbit
lince	lynx
llama	llama
lobezno	wolf cub
lobo	wolf
lutria	otter
mapache	raccoon

mapurite	skunk
marmota	marmot
murciélago	fruit bat
mustela	weasel
ñu	gnu
nutria	otter
ocelote	ocelot
orix	oryx
osezno	bear cub
oso, a	bear
oso colmenero	little anteater
oso gris	grizzly bear
oso hormiguero	great anteater
oso marsupial	koala
oso negro	black bear
oso pardo	brown bear
oso polar	polar bear
pájaro carpintero	woodpecker
paleto	fallow deer
pantera	panther
pécari	peccary
perezoso	sloth
petigrís	common gray squirrel
picamadero	woodpecker
piscívoro, ra	piscivorous, fish-eating
puerco	pig, swine
puerco espin	porcupine
rabopelado	opossum
ranero	frog pond
rangífero, rengífero, reno	reindeer
raposa, so,	fox
rata	female rat
rata amizclada	muskrat
rata canguro	kangaroo rat
ratón de campo	field mouse
ratón, na	male mouse
roedor	rodent
satirio	water rat
taltuza	gopher
tapir	tapir
tasugo, tejón	badger
tigresa	tigress
tigre	tiger
tigrillo	wild cat
tlacuache	opossum
topo	mole
unau	sloth
venado	deer
venado cola blanca	Whitetail deer
venado cola negra	blacktail deer
vicuña	vicuna
zarigüeya	opossum
zorra, ro	fox
zorrillo	skunk
zorro ártico	arctic fox
zorro de las praderas	kit fox, prairie fox
zorro rojo	red fox
zorro volante	flying fox

Pesqueria

acuoso	aqueous
aguas arriba	upstream
aleta dorsal	dorsal fin
alga verde	green algae
almatroque	shad net
alosa	shad
anzuelo	fish hook
ástaco	crayfish
barbilla	barbel
bentos	benthos
branquia	branchia
butrino	fish trap
cámbaro	crayfish
cangrejo	crab
carpa	carp
caudal	caudal fin or tail
cedazo	large fishing net
cercote	seine, fishing net
cetaria	fish hatchery
charal	a lake fish
cola	caudal fin or tail
crustáceo, a	crustaceous
desembocadura	inlet
desovar	to spawn

desove	spawning season, spawning
dorsal	dorsal
estanca	to dam up with beavers
estuario	estuary, inlet
fitoplancton	phytoplankton
fondo del lecho	streambed
freza	spawning of fishes
garlito	fish trap, snare
hueva	roe, fish eggs
ictiología	ichthyology
jaramugo	small bait fish
lago	lake
laguna	lagoon, small lake
límite de tamaño	size limit
lobina	bass
nansa	fish dip net
ninfa	nymph
opercular	opercular
opérculo	operculum
papila	papilla
pesca	fishing, angling
pescado	fish
pescador	fisherman
pescados de caza	game fish
pescar	to fish
pesquería	fishing ground, fishery
pesquería, pesca	fishing trade
pez	fish
piscicultura	fish culture
piscifactoría	fish hatchery
piscívoro, ra	piscivorous, fish-eating
plancton	plankton
rabión	river rapids
rana	frog
ranacuajo	tadpole
rana leopardo	leopard frog
ranero	frog pond
rápidos	river rapids
raudal	torrent rapid stream
rebalsar	to dam up as with beavers
recial	river rapids
red	net, netting
redar	to catch in a net
redaya	river fishing net
regajal, regajo	stream, brooklet
remanso	backwater
represa	to dam up as with beavers
riacho, riachuelo	rivulet, stream, rill
ribera	bank, shore
río	river
río abajo	downstream
río arriba	upstream
rivera	brook, creek
sabalar	shad net
sábalo	shad
salabardo	dip net, scoop net
salamandra	salamander
salmón	salmon
salobre	brackish, briny
sapo	toad
sedal	fishing line
subacuático, ca	underwater, subaquatic
subálveo, a	layer under a river bed
térmico, ca	thermic, thermal
tirona	fishing net, seine
tramo fluvial	reach (of stream)
trucha	trout
ventral	ventral
ventrecha	fish belly

Botanica

abedul	birch
abeto (Abies)	fir
abeto blanco	white fire
abeto de Douglas	Douglas fir
abrojo	thorn, caltrop, thistle
agrostología	agrostology
aguileña	columbine
aladierno (Rhamnus)	buckthorn
álamo	poplar
álamo temblón	aspen tree
aleznado, da	pointed
alga verde	green algae
alhumajo	pine needles

alimonarse	for leaves to turn yellowish
aliso (Alnus)	alder
almorejo	foxtail
altamandria	knotweed (Polygonum aviculare)
altarreina	yarrow (Achillea millefolium)
amacollar	cluster of shoots
amarillar	for leaves to turn yellow
amelo	aster
amento	ament
androceo	androecium
anea	cattail, bulrush
antera	anther
antesis	anthesis
aquenio	achene
árbol	tree
arborescente	arborescent
arboreto	arboretum
arbusto	shrub
arce	maple
aristoso, sa, aristado	awned
arracimado, da	clustered
arrejonado, da	lanceolate
avena silvestre	wild oat
axila	axil
ballueca	wild oat
baya	berry
belcho	joint fir, ephedra
bellota	acorn
bianual	biennial
bífero, ra	biferous
bífido, da	bifid
bionte	biont
biota	biota
bíparo, ra	biparous
bipétalo	bipetalous
bipinado, da	bipinnate
bohordo	cattail reed
borlilla	anther
botánica	botany

botánico, ca	botanical
bráctea	bract
bracteado, da	bracteate
bracteola	bractlet
briófita	bryophyte
bulbo	bulb
bulboso, sa	bulbous
cabillo	stalk, stem
cacto, cactus	cactus
cadanego, ga	bearing abundant fruit every year
calicillo	verticil or whorl of leaves
cáliz	calyx
camara subestomatica	substomatal chamber
cámbium	cambium
cambute	legume
caña	cane, reed
caquexia or clorosis	chlorosis
carpelo	carpel
carvajo	oak tree
caulescente	caulescent
caulífero, ra	borne upon the stem
ceborrincha	wild onion
cedro	cedar
célula	cell
célula cavidad	cell lumen
célula oclusiva	palisade cell, guard cell
celular placa	cell plate
cerezo	cherry tree
champiñon	mushroom
cimoso, sa	cymose
ciprés	cypress
clorofila	chlorophyll
cofia	rootcap
coleóptilo	coleoptile
comprimido	appressed
conífero, ra	coniferous, conifer
corteza	cortex
dehiscente	dehiscent
dendrocronología	dendrochronology
dendroideo, a	arborescent
depósito de grava	gravel bar

dermico	dermal	fresno	ash (Fraxinus)
dicotiledón	dicotyledon	fronda	frond, leaf
dioico	dioecious	frondoso, sa	leafy
dipétalo, la	dipetalous	fruta	fruit
disépalo, la	disepalous	fungal, fungoso	fungal
drupa	drupe, stone fruit	fungo	fungus
efedra	ephedra (joint fir)	geniculado, da	geniculate
empotrado	embedded	germinación	germination
encino	oak tree	gimnospermo, ma	gymnosperm
endodermis	endodermis	girasol	sunflower
enebrina	juniper berry	glóbulo	globule
enebro	juniper	gramíneo, nea	gramineous
entrenudo	internode	granífero, ra	graniferous
epifito	epiphyte	grasilla	juniper resin
epigino	epigynous	gromo	bud, shoot
espiga	spike	guía terminal	terminal shoot
espigado, da	spicate	helecho	fern
espiguilla	spikelet	hembra	female
espina	thorn, spine on plants	herbario, ria	herbarium
espora	spore	heterófilo, la	heterophyllous
estaminado, da	staminate	hidrófilo, la	hydrophilous
estípula	stipule	hidrófito, ta	hydrophytic
estología	ethology	hipoginia	hypogyny
estolonífera	creeper	hojuela	leaflet
expulsado	extruded	hongo	mushroom, toadstool, fungus
fanerófita	phanerophyte		
fasciación	fasciation	imbricado, da	imbricate
fenología	phenology	indehiscencia	indehiscence
fibroso	fibrous	infero, ra	inferior, lower
ficología	phycology	inflorescencia	inflorescence
fisonomía	physiognomy	involucro	involucre
fitología	botany	involuta	involute
fitón	phyton	juncáceo	juncaceous
fitoplancton	phytoplankton	junípero	juniper
fleo	timothy	lanceado, da	lanceolate
flor	flower	latifolio, a	latifoliate
flora	flora	legumbre	legume
florecer	bloom, to blossom	lema	lemma
florescencia	florescence	lígula	ligule
flósculo	floret	liquen	lichen
foliado	foliose	lobulado	lobed
folículo	follicle	macolla	bunch/cluster of roots or flowers
formación	formation		

maple	maple
membrana	membrane
membrana primaria	primary wall
mesocarpio	mesocarp
mesofilo	mesophyll
mesófito	mesophyte
micelio	mycelium
micología	mycology
micrófito	microphyte
monocotiledon	monocotyledon
monoico	monoecious
muérdago	mistletoe
multicaule	having many shoots
multífido, da	multifid
multiflor	multiflora
musco, musgo	moss
nanacate	mushroom
navajitas	grama grass
nebral, nebreda	juniper grove
nebrina	juniper berry
nebro	juniper tree or shrub
negrillera	elm grove, poplar grove
nervio	nerve, vein
noceda, nogueral	walnut grove
nocedal	walnut tree, walnut tree, walnut
nódulo	nodule
nogal	pecan tree, pecan nut
nopal	prickly pear growth or thicket
nuez	nut, of any tree
obovado, da	obovate
olmeda	elm grove
olmo (*Ulmus*)	elm
panícula	panicle
paniculado, da	paniculate
parrón	wild grapevine
pecíolo	petiole
pedicelado, da	pedicellate
pedicelo	pedicel
pedículo	pedicle
pedúnculo	peduncle
pencudo, da	having fleshy leaves

perennifolia	evergreen
periantio	perianth
pétalo	leaf, petal
piña	pine cone, pine nut
pinabete	fir (*Abies*)
pinado, da	pinnate
pinatífido, da	pinnatifid
pincho	thorn, spine on plants
pineda, pinar	pine grove or forest
pino	pine, pine tree
pinocha	pine needle
piñon	pinon nut
pistilado, da	pistillate
pistilo	pistil
planta	plant
plantas, plantaje	plants (collectively)
plantas silvestres	wild plants
plasmodesmos	plasmodesmata
pleguete	vine tendril
pluma	feather
polen	pollen
pteridófito	pteridophyte
pubescente	pubescent, hairy
puntiagudo	pointed
rabo	flower stalk
racimo	raceme
radiado, da	radiate
radícula	radicle
raigambre	matted roots
raíz	root
raíz pivotante	taproot
ramilla	sprig, twig
ramillete	cluster, umbel
raquis	rachis
recortado, da	notched, indented
reliquia	relic
resina	juniper resin
reticulado, da	reticulate
retoño	shoot, sprout, sucker
rizoma	rhizome
robinia (*Robinia*)	locust
roble	oak
robleda	oak grove or forest

rusticano, na	wild plants
sabuco	elder
sácere	maple tree
saciña	willow (Salix incana)
salceda, do	willow grove
salguera, ro	willow
salicáceo	salicaceous
sauce	willow
saúco	elder tree, elderberry
sauce llorón	weeping willow
sauceda	willow grove
savia	plant sap
saxícolo	saxicolous, growing among rocks
semiflósculo	semifloret
semilla	seed
sépalo	sepal
septo	septum
sésil	sessile
seta	mushroom
sicómoro	sycamore
siempre verde	evergreen
simpétalo, la	sympetalous
tallo flora	flower stalk
talo	thallus
talofita	thallophyte
tamarisco, tamariz	tamarix
tarajal	small cedar patch
taraje	salt cedar
taxaceo, a	taxaceous
temblón	trembling poplar, aspen
tetrandro, a	tetrandrous
tetrapétalo, la	tetrapetalous
tomentoso, sa	tomentose
trébol	clover, trefoil
trífido, da	trifid
trifoliado, da	trifoliate
tubérculo	tuber, tubercle
tuberosa, sa	tuberose, tuberous
tuna	prickly pear fruit
tunal	prickly pear plant or thicket
tunera	prickly pear plant
umbela	umbel
unicaule	having only one stalk
uníparo, ra	uniparous
vaina	pod
vástago, vástiga	shoot, scion
vegetación	vegetation
velloso, sa	billous
vena	vein
vernación	vernation
verticilo	verticil
vesícula	vesicule
viña	vine
xerofilo, la	xerophilous
xerófito, ta	xerophytic, xerophyte
xilema	xylem
yema	bud
yema adventicia	adventitious bud
yema terminal	terminal bud
zarcillo	tendril

Forestales

a mano	hand (work by)
abeto de Douglas	Douglas-fir
abono químico	fertilizer (chemical)
acebolladura	ringshake
acidez	acidity
aclarear	to thin
aclareo	intermediate cut, thinning
aclareo de la parte inferior	thinning from below
aclareo, método de	thinning method
aclareo por lo alto	thinning from above
aclareo selectiva	selection thinning
acre, superficie medida en	acreage
acrogenous	producido en el apice
áfido	aphid
afilar	sharpen
agalla	gall
agricultura agronomía	agriculture agronomy
agronomía	agronomy
aguja	pine needle

aislamiento	insolation
albura	sapwood
almáciga, cama de siembra	seedbed
almácigas, enfermedad de las	damping-off
alogamia	cross-pollinate
altura	height
ambiental	environmental
ambiente	environment
anillar	to girdle trees
anillo annual	annual ring
apear	fell
ápice	top
apilamiento	pile
aprovechamiento	utilization
aprovechamiento de tierras	land use
aprovechar	exploit
aprovecho multiple	multiple use
arado de discos	disk plow
arar	to plow
árbol	tree
árbol de navidad	Christmas tree
árbol ornamental	ornamental (tree)
árbol promedio	average tree
árbol semillero	seed tree
árbol tipo	sample tree
arborea	relating to tree
arboreto	arboretum
arboricultor	nurseryman
área	area
área basal	basal area
arenoso	sandy
arrastrar	skid (logs)
asseradero	sawmill
aserrar	to saw
aserrín	sawdust
astilladora	chipper
atacar	to infest/to attack
azar	random
azulado de madera	bluestain
banda	strip, belt

barra de hendir	planting bar
barrenador	borer
bejuco	vine
belleza del paisaje	scenic beauty
bolsa	bag
bosque	forest
bosque de entresaca	selection forest
bosque parque	park-like forest
brinzal	seedling
brota, brote	shoot/sprout
brújula	compass
cable	cable
cadena	chain
caducifolia	deciduous
calidad del sitio	site quality
calvero	open space in forest
cama de siembra almáciga	seedbed
cámbium	cambium
caminata de muestreo	cruise-line
camino acceso	access road
caminos, red de	road system
campamento	camp
campo	field
cancrosis	canker
cantidad	amount
carbon	charcoal
carbonera	charcoal kiln
carcava	gully
cargar	to load
cecidia	gall-midge, nutgall
célula	cell
celulosa	cellulose
cenizas	ashes
censo	inventory
cepa	stump
cercar	fence (to)
cerco	fence
chapa de madera	veneer
ciclo de corta	cutting cycle
cienaga	meadow (wet)
cincel	chisel
cinta de medición	tape (measuring)

cinta diamétrica	diameter tape
clase de edad	age class
clase diamétrica	diameter class
clasificación arborea	crown-class
clasificar	to grade
clima	climate
clon	clone
clorofila	chlorophyll
clorosis	chlorosis
cobertura de follaje	canopy
codominante	codominant
coeficiente morfico	form factor
coetáneo	even-aged
colchón aplicar un	to mulch
colchón de materia orgánica	mulch
combate	control (pests)
combate, método de	control measure
comejen	termite
computadora	computer
conífera	coniferous cone (pine)
cono	cone (pine)
constitución normal	normal forest
contenido de humedad	moisture content
contrafuego	backfire
control de incendios	fire control
copa	crown of tree
corazón	heartwood
corola	corolla
corta	felling/cut
corta, ciclo de	cutting cycle
corta de generación	regeneration cut
corta de salvamiento	salvage cutting
corta diseminatoria	seed tree cutting
corta de entresaca	selective cut
corta preparatoria	preparatory cutting
corta total	clearcutting
cortafuego	fireline
cortar	cut (to fell)
cortas sucesivas	shelterwood system
corte anual	annual cut
corteza	bark
corto plazo	short term

cosechar	to harvest
costero	slab
crecimiento	growth
cromosoma	chromosome
cuadrilla de campo	field party
cuadro	table (of figures)
cubicación de árboles apeados	scaling felled trees
cubicación en pie	volume determination of standing trees
cuenca	watershed area
cuenca hidrográfica	watershed
cuerda	cord
cuesta	slope
cuidado cultural	stand improvement
cultivar	to grow, to cultivate
cuña	wedge
curva de nivel	contour line
daño	damage
dasometría	forest mensuration
dasonomía	forestry
datos	data
debastadora	de-barker
defectuoso	defective
dendrómetro	dendrometer
densidad	density
depósito de madera	log deck
desarollo	development
desarraigar	lift (seedlings)
desbrozadora	brush-cutter
descortezador	barkbeetle
descortezadora	debarker
descortezamiento	bark peeling
descortezar	peel (to)
desecho	litter (refuse)
desechos de la corta	slash
deshierbe	weeding
deshojar	defoliate
desmontar	to deforest
desperdicio	waste
despuntar	to top
desramar	lop (to)
desviación estandar	standard deviation

diámetro	diameter
diámetro al altura del pecho	d.b.h.
diámetro superior	top diameter
dique	dike
disetaneo	uneven-aged
distribución de muestra	sample distribution
distrito	district
divisora de aguas	watershed (boundary)
dominante	dominant
dosel, espesura del	crown-closure
duramen	heartwood
durmiente de ferrocarril	railroad tie
ecología	ecology
economía	economics
edad	age
edad, clase de	age-class
efecto	effect
enfermedad	disease
enfermedad de las almácigas	damping-off
entresaca	thinning
entresacar	to thin
envenenar	to poison
erradicar	eradicate
error de muestreo	sampling error
escala	scale (of map)
escarabajo	beetle
escolítido	bark beetle
esciafila	shade tolerant
especie	species
especie, exótica	exotic species
espesura del dosel	crown-closure
estacar	to make cuttings
estación	season (of year)
estadística	inventory
estadística forestal	forest inventory
estaquillado	cutting
estereoscopio	stereoscope
estigma	stigma
estimación	estimation

estratificación	stratification
estrato inferior	understory
estrato superior	overstory
eucalipto	eucalyptus
explotación forestal	logging (harvest)
explotar	exploit
exterminar	to eradicate
extracción	skidding
extraer	skid (logs)
faja	strip, belt
fango	silt
fenotipo	phenotype
fertilizante	fertilizer
fibra	fiber
fila	row
financiamiento	financing
fisiológica	physiologic
floema	phloem
forcicula	caliper
forestación	afforestation
forestal	related to forestry
fórmula	formula
fotografía aérea	aerial photo
franja cortafuega	firebreak
frecuencia	frequency
frondosa	broad-leaved
fuego	fire
fueste muerto	snag (dead tree)
fuste	stem (bole)
generación	generation
genotipo	genotype
germinación	germination
germinación retardada	dormant (seed)
grano de la madera	grain (of wood)
grua	loader (jammer)
grumo	clod
granizo	hail
guarda forestal	forest guard
guía terminal	leader (growth)
hacha	axe
helada	frost
helecho	fern

hendidura en el duramen	heartshake
herbicida	herbicide
herida	injury
hereditario	hereditary
híbrido	hybrid
hidrología	hydrology
hijuelo	sprout/shoot
hilera	row
hipsometro	hypsometer
hipsometro de sierra	saw blade
hojarasca	litter (leaves)
hongo	fungus
horticultura	horticulture
húmedo	moist
importe	amount
incendio de copas	crown fire
incendio forestal	forest fire
incendio superficial	ground fire
incisión de corta	undercut
incremento	increment
incremento medio anual	mean annual increment
infestar	infest (to)
infestación	intestation
ingeniero del distrito	district officer
ingeniero jefe del distrito	district ranger
injertar	to graft
insecticida	insecticide
insecto	insect
intensidad de muestreo	sampling intensity
intervalo	interval
intolerante	intolerant
inundar	flood (to)
inventario	inventory
inventario de bosques	forest inventory
investigación	research
investigación forestal	forest research
invierno	winter

labranza	soil cultivation
larva	larva
leña	cordwood
lignina	lignin
límite	boundary
limpia	cleaning (silv.)
litera	litter (ground)
longitud	length
macizo, masa	stand (of trees)
madera	wood/timber
madera aserrada	lumber
madera blanda (de conífera)	softwood
madera contrachapeada	plywood
madera de desenrollo	peeler (log)
madera de pulpa	pulpwood
madera dura (de especie frondosas)	hardwood
madera en pie	standing timber, growing stock
madera en rollo	round wood
madera para aserrar	sawtimber
maderable	mature stand
madurez	maturity
maduro	mature
malezas	weeds (brush)
manejo forestal	forest management
mantillo	duff
mantillo ácido, humus	humus
mapa	map
marcar	blaze (on a tree)
masa	volume (of a stand)
matarrasa	clearcut
matarrasa en fajas alternadas	clearcut strips
matarrasa por grupos	clearcut patches
material defectuosa	cull (material)
matorral	scrub (growth)
media	mean
medición de volumen	scale (timber)
medida	measure
medida tabla	board measure

medula	pith
mejoramiento	improvement (forest)
mensuración	mensuration
método de combate	control measure
micorriza	micorrhiza
micosis	fungal disease
microclima	microclimate
moho	mold
mojón	survey monument
monoico	monoecious
monte	forest
monte bajo	coppice
monte bravo	saplings (thicket)
monte campesino	farm woodlot
monte coetáneo	even-aged forest
monte disetáneo	uneven-aged forest
morfología	morphology
motosierra	chainsaw
muebles	furniture
muérdago	mistletoe, dwarf-mistletoe
muestra	sample
muestreo	sampling
muestreo estratificado	stratified sample
multiplicación agamica	vegetative reproduction
multiplicación sexual	sexual reproduction
musgo	moss
nivel	level (instrument)
nivel, curva de	contour line
nudo	knot
nudoso	knotty
nuez	nut
objectivo de manejo	management objective
oquedal	high forest
ordenación del aprovechamiento	regulation of cut
ordenación forestal	forest regulation
ordenación por área	area regulation
ordenación sección de	management unit
ordenación por volumen	volume regulation
oruga	caterpillar
otoño	autumn
paisaje	landscape
pala de hendir	planting-bar
pantano	marsh
parasitario	parasitic
parásito	
parcela	plot
parcela de prueba	sample plot
parénquima	parenchyma
pasta de madera	wood pulp
pendiente	slope
perdigal	pole stage
período de aprovechamiento	working plan period
período de corta	cutting period
período de reposo, dormancia	dormancy
peso	weight
pesticida	pesticide
pie-tabla	boardfoot
piña	cone (pine), pinecone
pinar	pine forest
pino	pine (Pinus)
plaga	pest
plan de manejo	management plan
planeamiento	planning
plano	map
plano general	base map
planta	plant
planta leñosa	woody plant
plantación	plantation
plantadora	planting machine
plantar	to plant
plantar con terrón	ball planting
plantones	planting stock
plántula	seedling
platabanda	nursery bed
poda	pruning
poda de raices	root pruning

podar	to prune
podredumbre	rot
polilla	moth
polinizar	to pollinate
política forestal	forest policy
polón	stump sprout
polución del agua	pollution (water)
polución del ambiente	pollution (air)
por ciento	percent
porcentaje	percentage
posibilidad de corta	allowable cut
poste	pole
práctica cultural	cultural practice
pradera	meadow
presupuesto	budget
primavera	spring (season)
prism	prisma
procedencia	provenance
producido en el ápice	acrogenous
producto secundario	by-product
promedio	mean
proporción de la copa	crown ratio
prueba, parcela de	sample plot
pruebas, tomar	to sample
pua para injertar	scion
pudrición del corazón	center rot
pulpa de madera	wood pulp
quemar	burn
raices capilares	hair roots
rajar	to split
ralear	to thin out
rasa, raso	clearcut area
rascar	to blaze, to mark
rastra	harrow
rastrear	to harrow
rayo	lightning
recreo	recreation
recursos	resources
recurso natural	natural resource
red de caminos	road system
redecilla	reticulum of a ruminant
reforestación	reforestation
regar	to water (irrigate)
regeneración	regeneration
regeneración artificial	artifical regeneration
regeneración natural	natural regeneration
regla de Biltmore	Biltmore stock
relámpago	lightning
relascopio	relascope
rendimiento	yield
rendimiento anual	annual yield
rendimiento de aserrar	lumber yield
rendimiento sostenido	sustained yield
renuevo	shoot, sprout
repicados	transplants
repoblado	seedling stage
residuos de la corta	slash
resina	resin
rociar	to spray
rollizo/rollo	bole/bolt (of timber)
rotación	rotation
roya	rust (disease)
roya vesicular	(Cronartium)
roza a fuego	broadcast burn
rozar	to clear land
sabana	savannah
savia	sap
secadero	dry-kiln
secar	to dry/season
secado al aire	air dry
seguridad	safety
selección	selection
sembradora	seed drill
sembrar	to plant
sembrar a voleo	broadcast seeding
semilla	seed
semilla de primera categoría	selected seed
semillón	seedling
señalar árboles	to mark trees
serie de corta	felling-series
serraduras	sawdust

siembra	seeding
siembra en hileras	drilling (seed)
siempre verde	evergreen
sierra	saw
sierra cinta	bandsaw
sierra circula	circular saw
sierra trozadora de cadena	chainsaw
silvicultural	silvicultural
silvicultura	silviculture
sistema	system
sistema silvicultural	silvicultural system
sitio, calidad del	site quality
sobremaduro	overmature
sombra	shade
suelo forestal	forest soil
superficie	area
suprimido	overtopped, suppressed
surco	furrow
tabla	table (of figures)
tabla/tablón/cuadro	board, table
tabla de volumen	volume table
tabla de rendimiento	yield table
tablero de partículas	chipboard, particle-board
taladro	increment borer
talar	cut (to fell)
talarasa	clearcut
talarasa con portagranos	seed-tree method
tallar simple	coppice
tasa de interés	interest rate
tasación	appraisal
tejamanil	shake (heartshake)
tejido cicatrizal	callus
temperatura	temperature
tenazas	tongs
termita	termite
terreno baldío	wasteland
terreno forestal	forest land
terreno llano	level (ground)
terreno productor	productive forest land
tiempo	weather
tipo de interés	rate of interest

tipo de vegetación	vegetation type
tipo del suelo	soil type
tizón	blight
tocón	stump
torcida	spiral (grain)
torre de vigilancia	lookout tower
trabajo de campo	field work
tractor	tractor
tractor oruga	drawler tractor
tramo	cutting block
trasplantar	transplant
tratamiento cultural	stand improvement
trementina	turpentine
triplex	plywood
troceadora	chipper
tronco	stem/bole
trozador	crosscut saw
tronzar	to buck
trozo de madera, leño	log
turba	bog peat
umbrofila	shade tolerant
unidad de área	unit (of area)
unidad de manejo	unit (management)
unidad del organización	unit (organization)
utilización	utilization
valor corriente	market value
valor de madera en pie	stumpage (value)
vegetación	vegetation
vender en pie	to sell stumpage
vereda	trail (path)
verruga	burl
verticilo	whorl (of branches)
vía de extracción	skid trail
viga	beam
vigor	vigor
viña	vine
viruta	chip
virutilla	excelsior
vivero	nursery, nursery bed
volumen	volume
volumen en pie	standing volume

volumen normal	normal growing stock
vuelco por los vientos	windthrow
xilema	xylem
zona anual de crecimiento	annual cut

Suelos

abanico aluvial	alluvial fan
acidez	acidity
ácido	acid
acuico	aquic
adoguina	desert pavement
agregado	aggregate, soil
álcali	alkali
alcalino	alkaline
alófana	allophane
aluvial, aluvional	alluvial
aluvión	alluvium
aluvionamiento	accretion
álveo	streambed, riverbed
análisis mecánico	mechanical analysis
antrópico	anthropic
apedal	apedal
arcilla	argillic clay
arcillar	to loam
arcillo arenoso	sancy clay
arcilloso, sa	clayey, argillic
arena	sand
arena francosa, franca	loamy sand
arenal	sandy ground or place
argila, argilla	argillic, clay
argiloso, sa	clayey, argillic
aterramiento	aggradation, siltation
autoclave	autoclave
azonal	azonal, soil classification
baldío, tierras de	badlands
barniz del desierto	desert varnish
barro	clay mud, silt
barroso, sa	clayey
brecha	breccia
cabeza	peak, high hill
cala	soil pit
calcáreo	calcareous
cálcico	calcic
caliche	alkali
cámbico	cambic
cantalinoso, sa	stony, rocky ground
capa arable	top soil
capa dura, tosca	hardpan
capa impermeable	impermeable layer
carga de raja	cleavage
carga solida	bedload
catena	catena
colluvión	colluvium
coloide del suelo	soil colloid
concreción	concretion
cono de deyección	alluvial fan
consistencia del suelo	soil consistence
costra	soil crust
cuenca hidrográfica	drainage basin
depósito de grava	gravel bar
derrumpe	landslide
desgastar	to erode
deslizamiento de suelo	soil creep
deslizamiento deslavado	soil, degraded
deslizamiento eluvial	soil, eluvial
deslizamiento, profundidad del suelo	soil, depth
desprendimiento de ribero	bank erosion
duna	sand dune
durnudo	durinode
durstrato, duro	duripan
edáfico, ca	edaphic
edafología	edaphology
edafólogo	edaphologist
eluviación	eluviation
embancamiento	accretion

encalado	liming, soil
eólico	eolian
ercilla	loam
erosión	erosion
erosión acelerada	accelerated erosion
erosión de carcavas	gully erosion
erosión laminar	sheet erosion
erosión por regueros	rill erosion
erosión superficial	splash erosion
escorrentia, escurrimiento	runoff
espódico	spadic
estribo	abutment
fase	phase
floculación	flocculation
forma terrestre	landform
franco arcillo arenosa	sandy clay loam
franco arcillo limoso	silty clay loam
franco areilloso	clay loam
franco limoso	silt loam
friable	friable
frontón pendiente	pediment
granuloso	granular
grava	gravel, coarse sand
greda	clay, loam
gredal	clayey, loamy
guijarral	cobbly land
guijarro	cobble
guijoso, sa	gravelly, stony
histico	histic
horizonte edáfico	soil horizon
humedad del suelo	soil moisture
iluviación	illuviation
iluvial	illuvial
investigación de suelos	soil survey
lecho de roca	bedrock
liego, ga	virgin soil
limo	silt
lítico	lithic
litosecuencia	lithosequence

lixiviación	leaching
loess	loess
medano	sand dune
mesico	mesic
microrelieve	microrelief
molico	mollic
ocrico	ochric
oxico	oxic
paralítico	paralithic
podología	pedology
pedólogo	pedologist
pedón	pedon
pedregal, pedroche	stony ground
pedregoso, sa	stony
pedrejón	boulder
pedrera de erosión	erosion pavement
pena	rock, boulder
peniplanicie	peneplain
percolarse	percolate
perfil del suelo	soil profile
pergélico	pergelic
placas, en	platy
podzol	podzol
porosidad edáfica	soil porosity
pozo agrológico	soil pit (study)
profundidad de suelo	soil depth
regolita	regloith
riachuelo	rills
roca	rock
rocalia	pebbles, stones
sábulo	coarse heavy sand
sacamuestras	sampler
salico	salic
sobrecarga de suelo	overburden
sonda de tierra	soil auger
substrato duro	duripan
subsuelo	subsoil
suelo	soil, earth
suelo ácido	acid soil
suelo alcalino	alkaline soil
suelo calizo	calcareous soil
suelo castaños	chestnut soil
suelo clímax	normal soil

suelo coluvial	colluvial soil
suelo deslavado	degraded soil
suelo eluvial	eluvial soil
suelo eólico	aeolian soil
suelo esquelético	skeletal soil
suelo franco	loam soil
suelo franco arcilloso	clay loam soil
suelo humifero	muck soil
suelo inmaturo	immature soil
suelo maduro	mature soil
suelo, manto de	soil mantle
suelo mineral	mineral soil
suelo neutro	neutral soil
suelo orgánico	organic soil
suelo salino	saline soil
suelo sedentario	residual, primary soil
suelo vegetal	top soil
suelos, series de	soil series
térmico	thermic
terreno abarrancado	badland, clay loam
terrón	ped, earth clod
textura del suelo	soil texture
tierra	dirt, soil
tierra franca	loam soil
tierras de baldío	badlands
tierra plan	backfill, fill
tipo del suelo	soil type
tosca, arcillosa	clay pan
tosca, capadura	hard pan
turba	peat
údico	udic
ústico	ustic
xérico	xeric

Fauna Silvestre

abiótico	abiotic
abomaso	abomasum
abazón	cheek pouch
accípitre	accipiter
actividad	activity
acuático	aquatic
aguardadero, aguardo	hunter's blind
águila	eagle
aguilera	eagle's nest
alanés	species of large deer
alavanco	wild duck
alce	elk, moose
alero	buck, immature
alicante	viper
alimaña	predator
alimañero	predator control specialist
alimenticio	food value
alimentación	nourishment
alpinismo	mountain climbing
alzapié	snare
amaitinar	to stalk
anadeja, anadino, na	duckling
anaeróbico	anaerobic
añagaza	decoy/lure
anatomía	anatomy
anfibio	amphibian
anidar	to nest
anillo	annulus
anta	elk
aovar	to lay eggs
apitonar	to break out of egg shell using the bird's beak
área superpoblada	concentration area
artrópodo, da	arthropod
asaeteador	archer, bowman
asta	antler
astado	horned, with horns
atóxico	non-poisonous
atrapar	to trap
autopsia	autopsy
ave acuática	waterfowl
ave cantora	songbird
ave de caza	game bird
ave de presa	bird of prey
aves insectidarias	insectivorous birds
aves migratorias	migratory birds
avispa	wasp

balido	bleating sound of deer, sheep, goats
bandada	covey of birds
barba	beard
bifurcado, da	bifurcate
biológico, ca	biological
biólogo	biologist
biometría	biometry
bioquira	rattlesnake
bípedo, da	biped
bisulco, ca	cloven hoofed
bóvido	bovid
bovino, na	bovine
brama	mating season of animals (rut)
bramadero	rutting or mating place
cacería	hunt, hunting
cachillada	litter of animals
cadañera	giving birth annually
cagarruta	deer, rabbits or sheep fecal pellets
camada	litter, brood of animals
cánido	canid
canino	canine
cantidad permitible	bag limit
capacidad de caza	kill ratio
capacidad de carga cinegética	carrying capacity
caprípedo, da	split-hoofed, like goats
carnada	bait
carnicol	toe of cloven-footed animal
carnívoro, ra	carnivorous
cascabel, serpiente de	rattlesnake
cascudo, da	big-hoofed animal
caudimano	having a prehensile tail
cavernícola	cave dwelling
caza	to hunt
caza mayor	big game
caza menor	small game
caza menor deportiva	upland game
cazar	to hunt
cazadero	hunting ground
cazador, ra	hunter
cazador de alforja	trapper
cazador de cabezas	head hunter
cazador furtivo	poacher
cazar	to hunt
cebo	bait
celo	heat (female in season)
censo de caza	game census
cerceta	fawns first growth of antlers
cervato	fawn
cérvidos	cervidae
cetrería	falconry/hawking
chifle	bird call
chillido	decoy call
cíclico	cyclic
ciclo	cycle
ciclo vital	life cycle
cisípedo	digitate
cobijo	game cover
coeficiente de digestibilidad	digestion coefficient
cohorte	cohort
cola	tail of an animal
colmillo	canine tooth
comportamiento	behavior
connatural	innate, inherent
connaturalización	acclimatization, adaptation
conservar	to conserve
control biológica	biological control
coto de caza	game preserve
cría	brood of chicks
criadero	breeding place
crótalo	rattlesnake
cuadrupedo	quadruped
cuerno	horn of animals
cuero	skin, hide
culebra	small snake
culebrón	large snake
densidad	density
depredación	depredation
descogotar	to cut off the antlers

descubridero	lookout post
desemplumar	to pluck feathers off
desencarnar	to debone meat
desentrañar	to disembowel
deserción	desertion
desmogar	to shed horns
desmogue	shedding of horns
destripar	to eviscerate
diente	tooth, tusk, fang
dieta	diet
digestibilidad	digestibility
digitado	digitate
dispersión	dispersion
distribución	distribution
diversidad	diversity
dócil	docile
echadura de pollos	brood of chicks
ectoparasito	ectoparasite
embrión	embryo
encenagarse	to wallow
encodillarse	to hide in an inaccessible portion of a burrow
encogollarse	to tree
endogamia	inbreeding
enjundia	animal fat
entrañas	entrails
entremezcladura	interspersion
equilibrio	equilibrium
equino	equine
escape	escape, flight
escodadero	place where bulls, bucks, rub the velvet from their antlers
escondedero	hiding place
especialista	specialist
especie	species
especie indicador	indicator species
espécimen	specimen
esplique	bird snare
estético	aesthetics
estimación de pastizales	range reconnaissance
exótico	exotic

exployada	display with outstretched wings (birds)
extinción	extinction
extincto	extinct
falcónidos	falcons, eagles, birds of prey
fardacho	lizard
fauna	fauna
fecundidad	fecundity
fecundizar	to impregnate, inseminate
fenotípico, ca	phenotypic
fenotipo	phenotype
feral	feral
fertilización	fertilization
fetal	fetal
feto	fetus
fiera	wild animal or beast
filogenia	phylogeny
gallináceo	gallinaceous
gallo	cock, rooster
gamezno	small or young deer
gamitar	to sound a deer call (as with a deer call)
gamitido	call of deer (bleet)
garra	claw, talon
gata, o	cat
genotipo	genotype
gestación	gestation
gorrín	piglet, suckling pig
graznar	to cackle, caw, croak
graznido	caw, cackle, croak
gregario, a	gregarious
guácharo, ra, guacharro, ra	fledgling
guajolote	wild turkey
guardabosque	game warden, ranger
guarida	den, lair
guarnigón	young quail
guión	the leading bird of a migratory flock, or leading dog in a pack
habitación, habitat	habitat

halconería	falconry, hawking
hemacrimo	cold-blooded
hematermo	warm-blooded
hembra	female
herbívoro	herbivorous, herbivore
heterogeneidad	heterrerogeneity
hibernación	hibernation
híbrido, da	hybrid
homeotermo, ma	homeothermal
huella	animal track
huevo	egg
hurera, huronera,	hole, burrow
husero	straight antler of a deer
huta	hunters blind, hut
ijada	flank of an animal
incubación	incubation
incubar	to incubate
inmaturo, ra	immature
inseminar	to impregnate, inseminate
innato, ta	innate
interacción	interaction
inventario	inventory
invertebrado, da	invertebrate
jabado, da	mottled
lactancia	lactation
lagartija	lizard
lagartija cornudo	horned lizard
lepóride	leporid
ley de caza	game law
licencia	license
longevidad	longevity
macho	male
madriguera	hole, burrow
mamario, ria	mammary
mamífero	mammalian, mammal
manada	herd, flock
marsupial	marsupial
medidas en bruto	strip count
metabólico	metabolic
migración	migration
mimetismo	mimicry
mogote	budding antler
monogamia	monogamy

montería	big game hunting
montero	hunter
mortalidad	mortality
movilidad	mobility
muta	pack of dogs
mutualismo	mutualism
mutualista	mutualist
natal	natal
natalidad	natality
nativo, va	native, indigenous
natural	natural
neutralismo	neutralism
neutralista	neutralist
nidada	brood nest of eggs or newly hatched birds
nidal	nesting place, box
nidificar	to nest
nido	nest
niego	newborn falcon
nutrición	nutrition
observador de pájaros	bird watcher
omnívoro, ra	omnivorous, omnivore
ornitología	ornithology
orzuelo	bird snare, or animal trap
osera	bear's den, lair
oveja	female sheep
ovíparo	oviparous
pájara, ro	bird
pajarear	to hunt birds
pajarera	aviary
palmeado	palmate
palmípedo	webfooted
paludoso, sa, pantanoso	swampy, boggy
pantano	swamp, bog
panza	stomach
paradislero	hunter lying in wait
paranza	hunter,s blind, hut
parasítico, ca	parasitic
parasitismo	parasitism
parasito, ta	parasite
parvada	flock of birds

pastizal tipo	key area
pata	paw, foot
patihendido, da	cloven-hoofed
pato	duck
patón	big-footed
pava, pavo	turkey
pavada	flock of turkeys
pechuga	breast of a fowl
pelaje	peleage, hair
pelechar	to grow a new coat of hair, feathers
pelicano, na	gray-haired
pelicorto, ta	short-haired
pelo	hair, fur
pellejo	skin, hide
perdigana, perdigón	young partridge
perdiz	partridge, ptarmigan
peregrino, na	migratory (birds)
períodico, ca	periodic
pesticida	pesticide
pesuña, pezuña	hoof (cloven-hoofed animal)
pico	bill, beak of bird
pista	track, trail of an animal
pitón	budding horn of goat, deer
plaga	climactic zone
plumaje	plumage
plumón	bird down
plumoso, sa	feathery, downy
población	population
polla	pullet
pollada	covey, brood
ponzoña	poison, venom
predator	predator
preñada	pregnant
prensil	prehensile
quiste	cyst
rabicán, no	white-tailed
rábico	rabid
rabo	tail
radio	radius
raleón, na	bird of prey

raposera	fox hole, burrow, den
rapaces	raptors
raspa	beard
ratonera	nest of mice
rebaño	flock
recepto	shelter, refuge
reclamar	to decoy, lure/call with decoy whistle
reclamo	bird decoy, decoy whistle or call
reclutamiento	recruitment
recreación	recreation
recursos naturales	natural resources
redecilla	reticulum of a ruminant
refugio	refuge
refugio de caza	game refuge
reglamentación de caza caza	game management
remoto, ta	remote
repoblar	to repopulate
reptil	reptile
reserva primitiva	primitive·area
resguardo natural	escape cover
respiración	respiration
restauración	restoration
revolcadero	wallowing place of animals
ritmo	rhythm
ronca	rut, rutting season
roncar	to call the doe (as a buck in rut)
rostro	rostrum
rumen	rumen
rumia, rumiadura	rumination
rumiante	ruminant
rutina	routine, habit
saco aéreo	air sac, cell
saco vitelino	yolk sac
salvaje	wild, untamed
salvajina, no	game meat
secreción	secretion
señuelo	decoy, lure
silbo	hiss, hissing
simbiosis	symbiosis

simbiótico	symbiotic
solitario	solitary
tectriz	covert
tejonera	badger burrow
telemetría	telemetry
temporada abierta	open season
temporada cerrada	closed season
tendencia	trend
terrestre	terrestrial
terrícola	earth dwelling
territorial	territorial
torca	cave, cavern
trampa	trap, snare
trampero, ra	trapper
triangulación	triangulation
tullidura	bird of prey scats, droppings
ungulado	ungulate
vampiro	vampire
venado	deer
venado, carne de	venison
veneno	venom
vereda	path, trail
verriondez	estrus of swine and sheep
verriondo, da	rutting in swine or sheep
vertebrado	vertebrate
víbora	viper
víbora de cascabel	rattlesnake
vivíparo	viviparous
volateo	to shoot birds on the wing
vuelo	escape, flight
zanca	long leg of bird
zarpa	paw of large felines
zona climática	climatic zone
zona selvática	wilderness area
zorrera	fox hole
zurear	to coo (doves)
zureo	cooing (doves)

Pastizales

abundancia	abundance
acrecentador	increaser
acubilar	to gather cattle
acui	aguic
adaptación	adaptation
agronomía	agronomy
alambre de puas	barbed wire
albuhera, amanal	pond, stock tank
almarjal	marshland, swamp
alpestre, alpino, na	alpine
álveo	streambed
ambiental	environmental
ambiente	environment
amnícola	riparian, terrestrial
amplitud	amplitude
análisis	analysis
análisis cualitativo	qualitative analysis
análisis cuantitativo	quantitative analysis
analítico, ca	analytic, analytical
añojal	fallow land
anojo	yearling calf or lamb
arbustivo, va	shrub-like
apacentadero	pasture, grazing area
apacentar	to graze
aparcería	sharecropping
aprovechamiento	use, utilization
arboleda	orchard
arboledo	woodland
arbusto	shrub
arcabuco	dense woodland or brush thicket
arcabucoso	densely wooded
área basal	basal area
área de exclusion	enclosure
árido	arid
arredillar	to pen or corral
arroyar	to form gullies
arroyo	ephemeral watercourse
arroyuelo	brooklet
ártico, ca	arctic
aspecto	aspect
asocies	associes
asociación de plantas	plant association, community
atmosfera	atmosphere

autecología	autecology
auto fertilización	self-fertilization
autogamia	autogamy
autopolinización	self-pollination
avaluar	assess
badina	small shallow pond
barbechada	plowing of
barbechar	to plow
becerra	female yearling calf
becerro	yearling bull calf
bioma	biome
biomasa	biomass
biota	biota
biótico, ca	biotic
biótico, potencial	biotic potential
biotipo	biotype
bioclimatología	bioclimatology
biógeno, na	biogenic
biogeografía	biogeography
boalaje	pasture (area) for cattle
bode	male goat
bodón, estanque	ephemeral pond that dries in summer
boñiga	cattle dung
borregada	flock of yearling sheep
borrego, ga	yearling lamb, ewe
borreguero, pastor	shepard
borrica	female donkey
borusca	dry, fallen leaves or brushwood
boscaje	thicket
boscoso	densely wooded
bosque	woods, forest, woodland
bosta	horse, cow dung
bovino	bovine
brote	sprout, bud, shoot
brotadura	budding, sprouting
brotar	to sprout, bud
broza	litter, (leaves, branches)
brozoso, sa	brushy with undergrowth
burra	female ass
burrada	herd of donkeys, asses
burro	donkey, ass
caballada	horse herd
caballo	horse
cabezo	high hill, peak
cabra	female goat
cabrito, ta	young goat
caducifolia	deciduous
calverizo, za or calvero	with many open areas in the woods or forest
campiña	countryside
campo	field (the field)
cañada	gulch, ravine, big gulley
capa freática	groundwater
capacidad de pastoreo	grazing capacity
carnerada	flock of sheep
carnero	sheep, ram
carvajal	oak grove or wood
catadura	sampling
cebada	barley
cercado, cercamiento	enclosure
césped	sod
chamicera	area of burnt woodland
chamizo	half-burnt tree or log
chamuscar	to singe, sear, scorch
cienaga	marsh
clase de altura	height class
clase de cobertura de follaje	canopy class (foliage)
clase de condición del agostadero	condition class
clase diamétrica	diameter class
clase de edad	age class
clase vitamorfológica	life-form class
clasificación	classification
clasificación de pastizales	range classification
clima	climate
climático, ca	climatic
clímax	climax
coacción	coaction
cobertura vegetante	vegetative cover
cobertura cerrada	closed canopy
cobertura de follaje	canopy (herbaceous)

cobertura del pastizal	cover, range plant
cobertura del subsuelo	ground cover
coeficiente de aprovechamiento	proper use factor
cohorte	cohort
colladía	range of small hills
collado	mountain pass or small
hill	
competición	competition
comunidad	community
comunidad clímax	climax community
condición del pastizal	range condition
consoción	consociation
consocies	consocies
constancia	constancy
consumidor, ra	consumer
continuo	continuum
cosecha de forraje	forage crop
crianza	breed
cuadrato	quadrat
cuenca	watershed
cuesta	summit
cuesta, pendiente	slope, gradient
curso superior	headwaters
deciduo	deciduous
defecar	to defecate
defoliación	defoliation
defoliar	to defoliate
densidad	density
densidad de masa	stand density
densitómetro	densitometer
denso, sa	dense
derecho de pastoreo	grazing right
desarraigar, desenraizar	to pull up by the roots
desembocadura	mouth of river
desenraizar	plant uprooting
desierto	desert, wasteland
desmonte	felling or clearing of trees

dioicas	dioecious
dique de consolidación	check dam
dispersión	dispersal
dominante	dominant
ecología	ecology
ecológico	ecologic, ecological
ecólogo, ga	ecologist
ecotipo	ecotype
ecotono	ecotone
edáfico	edaphic
efectos del fuego	fire effects
embrosquilar	to gather cattle into a fold
empotrerar	to put cattle out to graze
encender	to ignite, set afire
encerradero	pen, sty or corral
encorralar	to corral cattle
endémico	endemic
enebral	patch or thicket of juniper trees
enraizar	to grow roots
entallecer	to grow shoots, sprout
entrecriarse	to grow among other plants
equilibrio	equilibrium
erosión	erosion
escabroso	rugged, rough terrain
especie	species
espécimen	specimen
estancado	stagnant
estanque	pool, pond, reservoir
estéril	barren
estiércol	manure
estrato	stratum
estrato inferior	understory
eutrófico	eutrophic
exposición	exposure
faciación	faciation
facies	facies
fachinal	marshland, marsh
fenología	phenology
fidelidad	fidelity
finquero	farm owner

fisonomía	physiognomy
fístula	fistula
fitogeografía	phytogeography
fitosociología	phytosociology
follaje	foliage
foresta	forest, wood, grove
forestación	forestation
forestal	related to forests or
forestero	forester, forest keeper
forestry	
forma biológica	life-form
forma de pastar	grazing habit
forraje	forage
forrajear	to forage
fotosíntesis	photosynthesis
fragoso, escabroso	rugged, rough terrain
frecuencia	frequency
fresquedal	area that remains green during dry season
fuego	fire
fuente, manantial	spring (water)
ganadería	cattle ranching or breeding
ganado	cattle
ganado caballar	horses
ganado caprino	goats
garma	steep slope, ravine
gradiente	gradient
graminívoro	grass-eating
granja	grange, farm
granjería	farming
granjero, ra	farmer
habitat	habitat
halófilo	halophytic
halófita	halophyte
haza	tract of arable land
hazuella	small tract of land
hemisferio	hemisphere
heno	hay
herbaceo	herbaceous
herbajar	to put cattle out to graze
herbaje	herbage
herbario	botanist, herbarium

herbazal	paddock, grassland
herbicida	herbicide
herbívoro	herbivore, herbivorous
hidrófito	hydrophytic
hidrología	hydrology
hidrometría	water current gauging
hidrosere	hydrosere
hiemación	winter blooming
hierba	forb, weed
hierba de césped	sod grass
hojarasca	litter
homogéneo, a	homogenous
horizonte	horizon
humedad	humidity
humus	humus
incendio	fire
incendio de bosques	forest fire
incendio del pastizal	range fire
inclinación de la pendiente	inclination, slope
índice	index
inventario	inventory
invernadero	wintering place
investigación	investigation
irrigación	irrigation
isla	island
isotermo, isotérmico	isothermal
jardín botánico	botanical garden
jehuite	weeds
jerarquía	hierarchy
lamedero	salt lick
latame	mulch, compost
lecho de inundación	floodplain
linio, hilera	row of tree, plants
llano	prairie, plain
lodoso	muddy, boggy
loma	hill
lote de pastos	range or grazing allotment
macho cabrio	male goat
maleza	weed (noxious)
malsano, na	noxious, harmful
manada	herd of cattle
manantial	spring (water)

manejo de cuencas	watershed management	parcela de ensayo	study plot
manejo de fauna silvestre	wildlife management	parcela experimental	experimental plot
		parcela de muestra	transect plot
masa	stand of trees	parición	parturition time of cattle
materia orgánica	organic matter	paridera	parturition place of cattle
materia seca	dry matter		
médano	sand dune, dune	parir	to give birth
mejoramiento	range improvement	parque	a park
mensuración	mensuration	paso de ganado	stock driveway
mesófito	mesophyte	pastadero	pastureland
método	method	pastadero libre	open range
metodología	methodology	pastadero permanente	yearlong range
microclima	microclimate	pastizal	pasture, pastureland
monoica	monoecious	pasto	hay, fodder, grass feed
montana	mountain	pastorear	to graze
Montañas Rocosas	Rocky Mountains	pastoreo diferido	deferred grazing
montanoso, sa	mountainous	pastoreo en rotación	rotation grazing
monte	woodland	pastoreo excesivo	overgrazing
montículo	knoll, mound (small)	pastoreo limitado	conservative grazing
montuosidad	ruggedness, wilderness	pastoreo prematuro	premature grazing
mosaico	mosaic	pastoreo selectivo	selective grazing
muestra	sample	pastura	pasture, fodder
nativo	native, indigenous	patullar, pisotear	to trample
naturaleza	nature	peñascal	rocky terrain
natural	natural	peñasco	steep rugged rock, crag
nicho	niche	pendiente	slope, gradient
nocible, nociva	noxious, harmful	perfil	profile
novilla	heifer	periódico, ca	periodic
novillada	drove of young cattle	período de pastoreo	grazing period
novillo	young buck	período vegetativo	growing season
nutrición	nutrition	picacho	sharp peak or summit
nutriente	nutrient	pie-acre	acre-foot
oligotrófico	oligotrophic	piedra	rock, stone
onda, ola	wave on water	planta indicadora	indicator plant
ordenación de montes	forest management	plantar	to plant
ordenación de la ganadería	livestock management	plantario, cama de siembra	seedbed, plant nursery
ordenación de pastos	range management	plasticidad	plasticity
orqueta	tree fork	pluviómetro	rain gage
otero	hill, knoll, butte	población	population
oveja	ewe	podar	to prune/trim a tree
ovejuela	small or young ewe	poliandro, ra	polyandrous
pacer	to put out to graze	polígamo, ma	polygamous

polímero, ra	polymerous
polinización	pollination
polución	pollution
potencial del pastizal	range condition
potrero	pasture, paddock
pradal, prado	meadow
pradejón	small meadow
presencia	presence
productor	producer
química	chemistry
químico	chemical, chemist
radiación	radiation
ramita	twig
ramón	browse, forage cut for fodder
ramonear	to browse
rancajada,	plant uprooting
ranchero	rancher
rancho	ranch
raso	clearing
rebano	flock of sheep
recolección	collection
recomidas	hedged
reconocimiento	reconnaissance
redecilla	reticulum (ruminant)
reforestación	reforestation
regadero	irrigation ditch
regadura	irrigation
regona	irrigation canel
relación	relationship
reliquia	relic
reserva	reserve
reservación	reservation
revegetación	revegetation
riberano, na, ribereño, na	riparian
rocalloso, sa	stony, rocky
Rocallosas Montañas	Rocky Mountains
rocoso, sa	stony, rocky
rumen	rumen
rumia, rumiadura	rumination
rumiante	ruminant

rumiar	to ruminate
sabana	savanna
sacamuestra	sampler
salega	salt lick
salgar	to feed salt to livestock
salinidad	salinity
salino, na	saline
salobre	saline ground
seca, sequía	dry season, drought
secadal	dry barren land
secaral	dry barren soil
sedimentación	sedimentation
sedimentario, ria	sedimentary
sedimento	sediment
selva	forest, woods
selvático, ca	of the woods
sembradora de hileras	seed drill
semiarbusto	half shrub
semiárido, da	semi arid
serrijón, serrania	short mountain range
sierra	rugged mountain range
sigmoideo, a	sigmoid
sillada	flat tract of land on mountain slope
sistema	systems
sistemático, ca	systemmatic
sitio	site
sobre pastoreo	overgrazing
sociabilidad	sociability
subafluente	tributary
subalpino, a	subalpine
subespecie	subspecies
substrato	substratum
subterráneo, a	subterranean
subtropical	subtropical
subvuelo	ground cover
sucesión	succession
sucesión primaria	primary succession
suelo	soil, earth
suelos, apeo de	soil survey
tastaña	hard soil crust
técnica	technique

tecnología	technology
temporada	season, period
tenada	cattle barn
teoría	theory
terracillas de sobrepastoreo	cattle terraces
terraplén	backfill
terrestre	terrestial
terrateniente	landholder
terreno, na	tract of land
terreno abarrancado	clay loam badland
terrón	ped, clod of earth
tierra	earth, soil
tipo de vegetación	vegetative cover
tocón	tree stump
tolerancia	tolerance
toriondez	rut of cattle
toriondo, da	in rut (cattle)
toro	bull
transpiración	transpiration
transecto	transect
trófico	trophic
tundra	tundra
ungulado	ungulate
vaca	cow
vacada	cow herd
vacuno, na	bovine
valor forrajero	forage value
valoración del pastizal	range appraisal
vaqueril	pasture for cattle
vaquero, ra	cowhand
varga	steepest part of hill or slope
vecera	heifer
vega	fertile lowland
vegetación	vegetation
vegetativo, va	vegetative
vequeril	pasture for cattle
veranada	summer season
veranadero	pasture used in summer
verano	summer
verdasca, ramita	twig
vigor	vigor
vitalidad	vitality
xerofita	xerophyte
xerofítico	xerophytic
yerbas	weeds, forbs
yermo	wasteland, barren land
zacatal	pasture land
zacate	grass
zacate amacollado	grass, bunchgrass
zona	zone
zona amortiguada	buffer zone
zonificación	zonation

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Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526